NUCLEAR ENGINEERING

VOL. 1 NO. 8 NOVEMBER, 1956

PRINCIPAL CONTENTS

page

CALDER HALL, OCTOBER 17, 1956
S.M. la Reine inaugure Calder Hall
Königin Elisabeth eröffnet Calder Hall
S.M. la Reina inaugura Calder Hall 321

NUCLEAR ENERGY AND THE EXPORT MARKET *by* **Dr. M. D. Wood**
L'Energie Nucléaire et le marché d'exportation
Kernenergie und Exportmarkt
La Energia Nuclear y el Mercaco de Exportación 325

CANADIAN REVIEW
Revue Canadienne
Kanadischer Bericht
Revista Canadense 329

THE WORLD'S REACTORS: NUMBER 7—RUSSIAN 5-MW POWER REACTOR
Les Réacteurs dans le Monde: Numero 7—Réacteur nucléaire de 5 MW (La Russie)
Reaktoren in der Welt: Zahl 7—5-MW Kernreaktor (Russland)
Los Reactores del Mundo: Numero 7—Reactor de 5 MW (Rusia) . . . . . facing 330

MECHANICAL INDUCED-DRAUGHT COOLING TOWERS *by* **D. J. Tow**
Tours de Réfrigération à tirage induit mécaniquement par aspiration
Kühltürme mit mechanischem Saugzug
Torres de Enfriamiento con tiro Mecánicamente Inducido 331

PROBLEMS OF LIQUID-METAL-FUELLED REACTORS *by* **B. R. T. Frost**
Problèmes soulevés par les Réacteurs à combustible métal liquide
Probleme der Flüssig-Metall-Reaktoren
Los Problemas de Reactores Alimentados con Metal Líquido 334

SWISS HEAVY-WATER RESEARCH REACTOR
Réacteur suisse d'Etudes à eau lourde
Schweizerischer Schwerwasser-Forschungsreaktor
Reactor Suizo a Agua Pesada para Investigaciones 340

ROLLING OF METALS UNDER LABORATORY CONDITIONS
Laminage des métaux dans les conditions en vigueur au laboratoire
Walzen von Metallen unter Laboratoriumsbedingungen
Laminado de Metales bajo Condiciones de Laboratorio 342

A 5-W LABORATORY REACTOR
Un Réacteur de Laboratoire de 5 W
Ein 5 W Laboratoriumsreaktor
Un Reactor de Laboratorio de 5 W 344

REGULAR FEATURES

EDITORIALS 317
COMMENTS ON THE NEWS . . 319
CORRESPONDENCE 346
WORLD NEWS 347
ORBITS IN INDUSTRY . . . 349
PERSONAL 351
TECHNICAL PAPERS . . . 352
NEW BOOKS 354
PROCESSES AND EQUIPMENT . 356
PATENTS REVIEWED . . . 358

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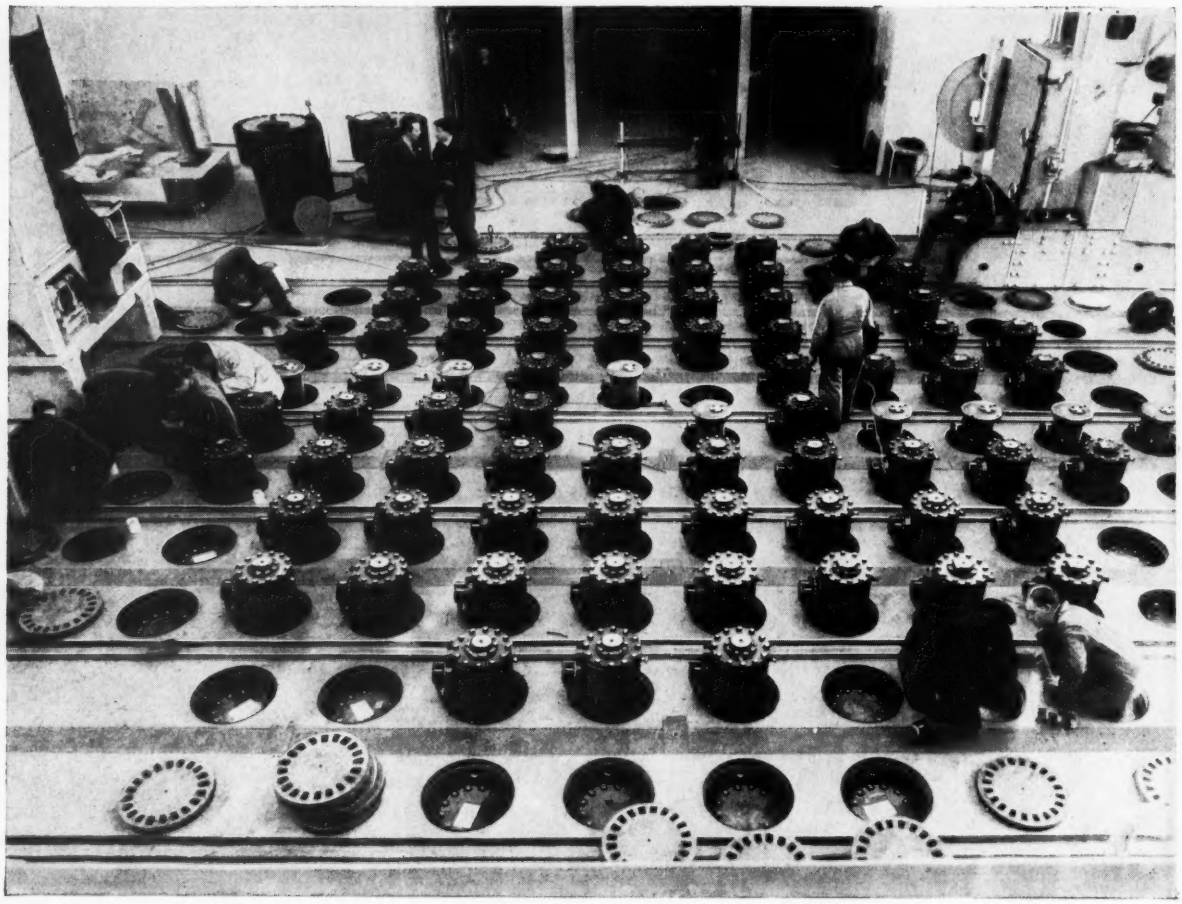

Controlling the reactors

AT CALDER 'A' Metropolitan-Vickers was responsible for the reactor control scheme and has supplied 120 actuating mechanisms and ancillary equipment. These mechanisms are for operating the combined control and shut-off rods and are arranged to provide a slow " out " and two faster " in " speeds. They will hold the rods in any required position and provide a controlled shut-off of the reactors independent of the electrical supply.

The pile cap during the installation of the control rod mechanisms at Calder Hall, Britain's first atomic power station. M-V is also responsible for the reactor control schemes at the Calder 'B' and Chapelcross power stations of the U.K.A.E.A., a further 360 actuating mechanisms being involved.

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NUCLEAR ENGINEERING VOL. 1 NO. 8 NOVEMBER, 1956

EDITORIALS

Small Power Reactor Systems

NOW that the United Kingdom's nuclear power programme is safely launched, with Calder Hall officially opened and tenders for both the C.E.A. stations and the S.S.E.B. station under consideration, greater attention will be paid to the development of reactor systems which are capable of producing electricity in small quantities at a cost comparable with that obtained from Diesel engines. Many systems are being considered both in this country and the United States, from the water-moderated reactor, with a now-considerable history of development, to the L.M.F.R. and H.A.R. systems at present in the research stage and the heavy-water sodium system only recently accepted by the A.E.C. for initial design and development. Other systems considered are the organic-moderated reactor, heavy-water reactor, the fluidized reactor and the high-temperature, gas-cooled reactor. Nearly all of these must be considered as long-term projects with a genuine development time of, say, ten years, although progress in the atomic energy field over the past ten years has been so rapid that few would be prepared to make any concrete estimations on the minimum development times that are achievable. Whilst the light-water-moderated reactor has received the most intensive overall development, considerable experience has been obtained on gas-cooled, graphite-moderated reactors, such as Calder Hall, which should speed up the development of the graphite-moderated, high-temperature, gas-cooled system. Furthermore, metallurgical considerations would indicate that the problems to be met in this system will not be so severe, although it is too early to be dogmatic even on this point.

Clearly, it is desirable that with the limited resources available in this country a decision must be made soon on the type or types that are to undergo intensive development and it would be convenient if the programme could be divided into two distinct sections, one of which can be thought of in terms of a quick development programme and the other a long development programme. It may not be possible within the next few months to determine the most advantageous long-term project, as long-term development implies the existence of considerable unknowns, but it is reasonable to suppose that present indications will lend a bias to one project and indicate a more intensive concentration on that than on other systems.

Apart from the technical considerations involved in the choosing of a new system, serious consideration must be given to such factors as ease of operation, cooling-water requirements, fuel-element burn-up and availability of fuel. The Nuclear Development Corporation of America, in its announcement on the Chugach heavy-water sodium reactor, emphasized the value of employing a fuel with a low enrichment factor. The significance of this is largely political rather than technical and will depend upon the type of restriction that governments are likely to impose on highly enriched, separable and pure fissile material. No clear statement has been made by any of the three major governments on their attitude towards this question. but the general impression that has been created over the past 12 months and exemplified at the recent international agency conference is that both the U.S. and the U.S.S.R. would be somewhat loth to sell outright highly enriched fuel, whereas the U.K. might be prepared to consider the proposition. This attitude is to be encouraged, as, irrespective of the paper agreements that are made to ensure that reactor fuel is not converted (however inefficiently) to military uses, a country determined to enter the atomic-bomb field would proceed with such conversion with a reasonable certainty that no serious countermeasures would be taken. There is every reason to suppose that. whatever nation committed such an act, it would find support in one of the main international blocs and would find support in its policy of the right of self-determination of its own acquired material. There can be little question that, in the years to come, highly enriched material will be a straightforward, marketable product only controlled by safety regulations such as might cover, say, dangerous chemicals. The implication is, therefore, that little purpose would be served in choosing a system on the grounds that it would be able to operate with lowly enriched fuel. Operation with natural uranium, on the other hand, could bring obvious advantages in fuel costs alone because of greater competition, so the difference between natural and slightly enriched uranium is much more marked than between slightly enriched and greatly enriched.

If the international agency fails to become an effective marketing agency of fissile material of all types without objectionable inspection or political restrictions being imposed, an opportunity would be created for Britain to become a major exporting country of enriched fuel. Quite apart from the Calder Hall and Chapel Cross stations and Capenhurst, the output from which will not always be directed towards the military programme, by 1965, assuming a generating capacity of 5,000 MW with a minimum heat rating of 15,000 MW and a conversion factor of not less than 0.7, the quantity of plutonium produced per year —entirely suitable for reactors but unsuitable for bombs— would amount to some four tonnes in this country alone.

Small Nuclear Power Systems

DURING the address by the Lord Privy Seal, Mr. R. A. Butler, prior to the opening of Calder Hall by Her Majesty the Queen, he made the statement that after 1965 it may well be that every new power station will be "atomic" and by 1975 the output from nuclear power stations will certainly be more than, and may be double, the total electrical output of all power stations that serve our needs for electricity.

This rapid expansion of the atomic energy programme has been envisaged now for some time, and present estimates indicate that an expansion of the magnitude described by Mr. Butler will barely be sufficient for our needs. In the report published by the Central Electricity Authority for 1955-1956, the increase in units sent out over the previous year amounts to 9.4%. If this rate of increase were to continue, the doubling time would be less than ten years. In fact, from 1948-1956 (the eight years which have elapsed since the responsibility for the electricity production in England and Wales was vested in the C.E.A.) consumption has increased by 93.7%. In their paper to the World Power Conference, Duckworth, Squire and Newman gave estimates of the total demand for the years 1965-1966, 1970-1971 and 1975-1976. These, expressed in million kWh, were respectively 136,000, 176,000 and 229,000, to be compared with a 1955-1956 figure of 63,000. This allows for a doubling period of slightly less than ten years between 1955 and 1965 but greater than ten years from then on. Only time will show whether this reduction in doubling time is justified.

By the end of March, 1956, the total installed capacity under the C.E.A.'s control was over 20,600 MW, with a total maximum output capacity of over 18,800 MW. The next five years envisage the construction of approximately 2,000 MW per year of installed capacity from fossil fuels, so that by 1965 the total expected demand of 136,000 million kWh can be met by an installed capacity approaching 37,000 MW from conventional stations and, say, 5,000 MW from nuclear power stations, provided that an annual load factor of 36% can be assumed for conventional stations, and 75% for the nuclear power stations. This would allow also a maximum output capacity of more than 36,000 MW to cater for the expected peak demand of 34,500 MW. If one assumes that the building of conventional power stations is discontinued as from 1965, and that the Vienna Conference figure for the expected demand is only a conservative estimate, nuclear power stations must be able to supply at least 125,000 million kWh per year by 1975. If an annual load factor of 70% can be assumed, this represents an output capacity of approximately 20,000 MW with an installed capacity of, say, 25,000 MW. The expected peak demand of 55,500 MW would be barely accommodated. It is improbable that so large a proportion of the total capacity could operate at this load factor, and a figure of 60% would be more accurate; this leads to an installed capacity of 30,000 MW with a peak output of nearer 60,000 MW.

On present estimates, therefore, an output from nuclear power stations which is double the total electrical output of all power stations that serve our needs for electricity today is in no way extravagant and may well be found to be insufficient.

Whilst the immediate expansion of the programme generally anticipated has not been published, it can be assumed that the installed capacity by 1965 will be in the region of 5,000 MW, representing an output from, say, 15 stations each with two reactors. Even allowing for an increase in the output of each reactor over the following ten years, something like 130 reactors will have to be built. These need not necessarily be grouped in pairs and will, near large industrial centres, no doubt be built in greater numbers. In the remoter areas, however, where transmission costs are relatively high, it may be more economic to build power stations with one reactor unit only with an output exceeding that of Calder Hall ("A" and "B").

These figures represent, of course, a tremendous building programme, but one that would have to be faced whether the prime source of energy were fissile or fossil fuel. The siting of the new stations, however, is liable to cause a great deal more thought, and we must accept in the very near future the idea of nuclear power stations being built near, and in, heavily populated areas.

There will be a few people directly in the atomic energy power development programme who would have much hesitation in advocating this move, once reasonable operating experience at Calder Hall and at, say, Bradwell and Berkeley had been obtained, but consideration of possible sites cannot wait for so many years.

It is believed that sites have already been selected for a number of the stations that were originally envisaged in the White Paper programme, but it would be worth while at this stage to consider the very much greater building programme that is ahead.

At the same time, there is much that can be done in the way of propaganda to condition the general public to the idea of nuclear power stations. It can be argued that, apart from difficulties over cooling water at Bradwell and considerations involving only the general architecture of the station rather than the nuclear energy aspects, little public concern has been encountered, but care should be taken that every effort is made to keep the public informed of atomic energy developments and to do everything possible to prevent a set-back that would result from a public inquiry which yielded only a little more unfavourable reaction than the last.

The World's First Nuclear Power House?

ONE of the more pleasing features of the opening of the Calder Hall station was the attendance of a large number of diplomatic and scientific representatives from countries overseas. The steady decrease in international jealousies is something that all will applaud, and we can view the little thrusts and parries between such representatives with a less-anxious air. The following are extracts from the speech by Academician Topchiev to Sir Edwin Plowden and Sir Edwin's reply on the occasion of the presentation to Her Majesty the Queen of an illuminated address and a film illustrating work in the U.S.S.R. on the peaceful uses of atomic energy: *Topchiev:* "It is with sincere joy that we greet your big step forward in the use of nuclear power for creative purposes and that we see that, after the world's first atomic power station was built in the U.S.S.R., a new huge nuclear power station has appeared in England." *Plowden:* "We in the United Kingdom Atomic Energy Authority are delighted that so many representatives of the atomic energy projects in other countries have been able to come to Calder Hall today to see the opening of the world's first industrial-size nuclear power station."

To satisfy national prides, we suggest: The First Nuclear Power House (U.S.S.R.); The First Nuclear Power Station (U.K.); The First Civilian Nuclear Station (U.S.A.).

Comments on the News

THE WINFRITH HEATH ESTABLISHMENT?

Yet another month has rolled by without a clear statement being made on the position regarding the new atomic energy establishment at Winfrith Heath, Dorset. It is understood that water tests and effluent tests have been completed for some time and that preliminary results were available many months ago. The responsibility for the delay must therefore lie with the Dorset County Council, whose understandable concentration on parochial matters is now beginning to have serious effects on the necessary expansion of the U.K.A.E.A.'s research facilities. It is recognized that the site for the establishment is of no use for farming land and is only little visited by countryside-loving tourists. The number of Hardy enthusiasts is not great and the conversion of Winfrith Heath into a tidy establishment is unlikely to cause them serious dismay. The main issue appears to concern the possible inducement to a small section of the local labour to change from farming to unskilled occupations on the new site. However the number of people involved that will affect the farms cannot be calculated in more than dozens at the most and there is a considerably greater section of the surrounding population who will welcome the arrival of an industrial organization to bring opportunities to young people who are technically minded.

The A.E.A. is to be commended on its restrained approach towards the negotiations and the obvious absence of a tendency to adopt steam-rollering techniques. The D.C.C., however, should not take advantage of this attitude and must be made to realize that more than local affairs are at stake. In this country we are jealous of the fact that Government departments can be restrained from by-passing local interests; but to retain these rights it is essential that local councils should be prepared to think in broader terms and to be prepared to accommodate programmes of this nature, unless the very strongest reasons exist against them.

CIVILIAN CONTRACTS

There has been much speculation on the terms of the tenders submitted by the four consortia to the C.E.A. for the stations to be built at Bradwell, Essex, and Berkeley, Glos., and to the South of Scotland Electricity Board for the station at Hunterston, Ayrshire, but full details of these will be available when the contracts are awarded early in the new year. In the meantime, it should be borne in mind that, whilst running costs will differ little from one station to another, the location of the station will considerably affect the capital cost. The significance of the civil engineering side of such a project is frequently underestimated and the building costs at Bradwell and Berkeley might differ from those of the Scottish site by as much as £20 per kW installed capacity, due to the different nature of the subsoil and rock strata and the provision that has to be made with the C.E.A. stations for building in an area liable to flooding. In quoting costs, therefore, of nuclear power stations and the effective cost per kW hour, due allowance must be made for the civil engineering problems associated with the site.

The C.E.A. and the A.E.A., and the S.S.E.B. and their consultants have an unenviable task before them in the next two months before the contracts are finally placed. The question must inevitably be posed as to who is to judge the excellence or otherwise of the submitted designs. There are strong arguments for the suggestion that, particularly on the heavy engineering side, as great a body of experience is assembled in the consortia as in the examining bodies. Furthermore, close co-operation has been kept throughout the development stage between the authorities and industry on the details of design. Some responsibility for these designs must therefore rest on those people who are now the judges. It must be assumed, of course, that the urgency of the programme will result in these three contracts being placed with different company groups and the assumption is therefore that the terms of the tenders, at least in three of the four cases, are substantially equivalent. If this proves to be not so, the C.E.A. and S.S.E.B. are in a peculiarly difficult position. They are faced either with the acceptance of designs which are below the top standard and of deciding between themselves which organization is to have the best—and the worst—or they will be forced to persuade one or more of the consortia to convert their designs to embody improvements (this would be a considerable task) or to manufacture to drawings supplied by one of the other groups. Preserving good relations in these circumstances would be singularly difficult. Has it been hoped, therefore, that such equality exists between three of the designs and that there is a definite difference between these three and the fourth to allow an easy choice to be made? But, again, this fourth company will be able to ascribe its misfortunes, at least in part, to the same organizations that have made the decision.

In the meantime, although the Secretary of State for Scotland has been able to consider from the beginning the proposals for a generating plant with a capacity between 250 and 300 MW, planning permissions exist at Bradwell and Berkeley for installed capacities of 200 MW only. It must be assumed that, in spite of this early mistake, no atempt will be made to run the stations when built at below their optimum rating, and in view of the public inquiry that was necessary at Bradwell it would be well if this matter was cleared up before construction began. Those who oppose the station at Bradwell may find in this mistake an excellent opportunity for reopening discussion, but it is to be hoped that national considerations will allow the necessary modifications to proceed to the order without the trouble and cost of another public inquiry.

SUBSIDIZING EXPORTS

Unrest at the apparent lagging by the United States programme for the development of nuclear power, largely brought about by the success of the United Kingdom's gas-cooled, graphite-moderated reactor programme, can force the U.S. Government into the position where subsidization of reactor power plants is necessary to ensure a large overseas market. The present trend of thought is shown by the proposals in the editorial of *Nucleonics* for September, which suggest that, to give impetus to the foreign programme, "we might pay for the difference between the cost of a conventional power plant of a particular size in a particular country and the cost of having U.S. industry build a nuclear power plant there, or may be the differential between operating costs should be basis for support". Because of the inherent large capital expenditure associated with nuclear power plants, this first suggestion would represent a very considerable subsidization of American plants and would certainly be a strong incentive for other countries to buy American goods. The implication is that, either because of higher manufacturing costs or, more probably, less-efficient designs, the U.S. is not able to compete with British industry on equal terms.

If such a government subsidization came into effect, the repercussions on British manufacturers would inevitably be serious and the effect, unfortunately, would not be confined

entirely to the atomic energy field. The question may then be posed as to the countermeasures that the British Government could make. Quite apart from the difference in the economic position of the two countries, which would certainly favour the United States industry in the long run if a cut-throat system of subsidization should develop, nuclear power plant manufacturers could not expect such Government assistance any more than car manufacturers could expect the Government to provide petrol for the first 5,000 miles of exported cars.

No doubt there would be some countries who would still buy British in spite of such American inducements and whose dollar reserves are so low that no dollar expenditure over and above that already laid down can be contemplated; but, in the main, we must accept the challenge that, only if our plant is cheaper to buy and run by an order of magnitude, could such competition be met. There is little doubt also that in the long run the implicit acknowledgment of design inferiority would weaken the U.S. position.

AMORTIZATION CALCULATIONS

Detailed discussions, as we have said before, on the cost of nuclear power in the United Kingdom must at least wait until the exact terms of the contracts are known and a final reckoning cannot be made until these stations have been in operation for some time, although operational experience at Calder Hall will allow very close estimates to be made. One of the most controversial aspects of cost calculations concerns the amortization rates that should be applied to the unconventional sections of the stations, and the charge is often made that the U.K. calculations are unrealistic because of the low investment charges that are used. These charges bear a direct relation to the average interest rates on investment obtaining in a country and it must be acknowledged that, in general, these are lower in the U.K. than in the U.S. Comparative figures give 6% (approximately) in the U.K. as compared to 10% or more in the U.S. Particularly with the high investment costs associated with a nuclear power station, this has a considerable effect on the cost per kWh in the same way as the operational load factor. Nevertheless, a rough calculation shows that the graphite-moderated, gas-cooled reactor would be still a highly competitive system in the U.S. when compared with other reactor systems under development, even if not with conventional stations. Taking as a first approximation Jukes' figures of 7 mils/kWh, this can be roughly divided equally into capital charge and running charges, so that even doubling the investment rate would lead to a figure of only 10.5 mils/kWh. In addition, constructional expenses in the U.K. are liable to be lower than those in the U.S. and, therefore, more realistic figures of 12 mils/kWh should be considered. This, as it stands, still compares favourably with the 14 mils that has been quoted as the possible cost from a pressurized-water reactor system. Furthermore, it is generally acknowledged that the Calder Hall station, which is now in operation, at least approaches Jukes' figure, whereas the Shippingport station, construction of which is still not complete, is expected to give power at a cost of 50 mils/kWh—a very large discrepancy. Calculations allowing for plutonium production have also been criticized as not being realistic, but it is believed that with the new C.E.A. stations a figure of 7 mils/kWh can be achieved without any allowance for this credit. On the other hand, it should be noted that fuel costs as quoted for American reactors are, to a large extent, unrealistic and are based on the existence of enrichment installations, the cost of which has been written off against the last war. Whilst it must be admitted therefore that electricity production by a Calder Hall type of station would cost more in the U.S. than in the U.K., there is every evidence to suggest that the real figures cannot be rivalled by stations using other reactor systems. We have previously suggested that there is no reason why reactors for U.S. utility companies should not be built by the U.K. where a lower investment rate can be accommodated, and consideration should be given by the Treasury to encouraging British companies to set up subsidiaries in the U.S. financed with British capital to exploit the growing nuclear power market.

NUCLEAR-POWERED MERCHANT SHIPS

The deputy director, division of reactor development, U.S.A.E.C., L. H. Roddis, in a statement before the Atomic Industrial Forum at Chicago in September, put the case for development in the U.S. of a nuclear-powered merchant vessel. He acknowledged that the first craft of this type would probably be an uneconomic proposition, but the valuable experience gained would lead to the early development of economic craft in the power range of 15,000 to 2,000 s.h.p. It was probable, he said, that capital costs would, for many years to come, remain comparatively high, but with the greater gross revenue possible these should be more than counterbalanced. This greater revenue would arise for a number of reasons. Larger cargoes could be carried because of the smaller size of the power plant and because of its probable smaller weight, longer runs would be possible at highly sustained speeds and quicker turn-round in ports because of the absence of refuelling operations.

The power plant for the first ship—designed to carry 100 passengers with a deadweight cargo capacity of 12,000 tons at a speed of some 21 knots — would probably be a pressurized-water type because of the wealth of experience now accumulated in the U.S., but the $42½ million voted by Congress provides for the development of other reactor systems. Six design feasibility studies are involved, three of which are particularly promising. These are the gas-cooled reactor with a closed-cycle turbine, the organic-moderated reactor and the boiling-water reactor. In the near future work will also be started on a super-critical water reactor and an aqueous homogeneous reactor. It is rather ironic to note that the class of vessel that would be particularly suitable for reactor propulsion is the oil tanker, where the tendency is to build ever-larger vessels and in which the bulk fuel can form part of the reactor shielding. It will be many years, however, before developments in reactor power stations and reactor propulsion units in any way limit the use of oil, and no large oil-carrying country is anticipating anything but a steady increase in its tanker fleet, both in size and number, for many years to come.

It is probable that the U.S.S.R. will be the first country to operate a nuclear-powered surface ship, as reports indicate that construction of the ice breaker incorporating a nuclear propulsion unit is well advanced. Many countries, however, are undertaking energetic research into the maritime application of atomic energy, and in the U.K. a conference was held on October 19 at which views on the latest developments could be exchanged between the A.E.A. and representatives of shipbuilding and shipowners' associations.

NUCLEAR WEATHER

In a statement recently, Mr. Von Neumann, a member of the U.S.A.E.C., predicted that in a matter of decades man would be able to control the climate. He raised also the prospect of such control being used as a means of warfare in a possible future conflict. There is no justification, however, for the rumours that experiments of this nature have been launched over Britain during 1956, either by hostile powers or by the British Government in an attempt to obtain early conditioning of the population to meet such eventualities.

But let us be fair! Although on October 16 the biting wind and lashing rain caused many hearts to sink in the Windscale area, October 17 dawned bright and sunny and, although the wind still blew (but not, mark you, with its accustomed force), the sun shone brightly on the day's events.

Her Majesty the Queen closes the switch to feed electricity from Calder Hall into the national grid.

CALDER HALL
October 17, 1956

AT 12.18 p.m. on Wednesday, October 17, Her Majesty the Queen inaugurated Britain's first nuclear power station when she switched the electricity produced at Calder Hall into the national grid. A large watt-hour meter on the roof of the administration building recorded the passage of electricity into the public-supply system.

Special switching arrangements were made so that when, in the afternoon, the Queen visited a new steelworks near Workington the plant went into operation using electricity produced by nuclear energy.

Sir Edwin Plowden, chairman of the U.K. Atomic Energy Authority, presents Lord Citrine, chairman of the Central Electricity Authority, to the Queen.

Speech by Her Majesty The Queen

TODAY, as power from Calder Hall begins to flow into the national grid, all of us here know that we are present at the making of history.

For many years now we have been aware that atomic scientists, by a series of brilliant discoveries, have brought us to the threshold of a new age. We have also known that on that threshold mankind has reached a point of crisis. Today we are, in a sense, seeing a solution of that crisis as this new power, which has proved itself to be such a terrifying weapon of destruction, is harnessed for the first time for the common good of our community.

In this turbulent century we have seen one technical revolution succeed another with astonishing speed. Within the span of a few generations our way of life has been transformed beyond anything our forefathers could have imagined. The age of steam was succeeded by an age of such startling achievement that we, who are close to it, can hardly realize that so short a period encompassed the invention of the motor car, the wireless set, the aeroplane and much else besides, which we now take for granted. So quickly have we learnt to accept the pace of modern development that we have been in danger of losing our sense of wonder.

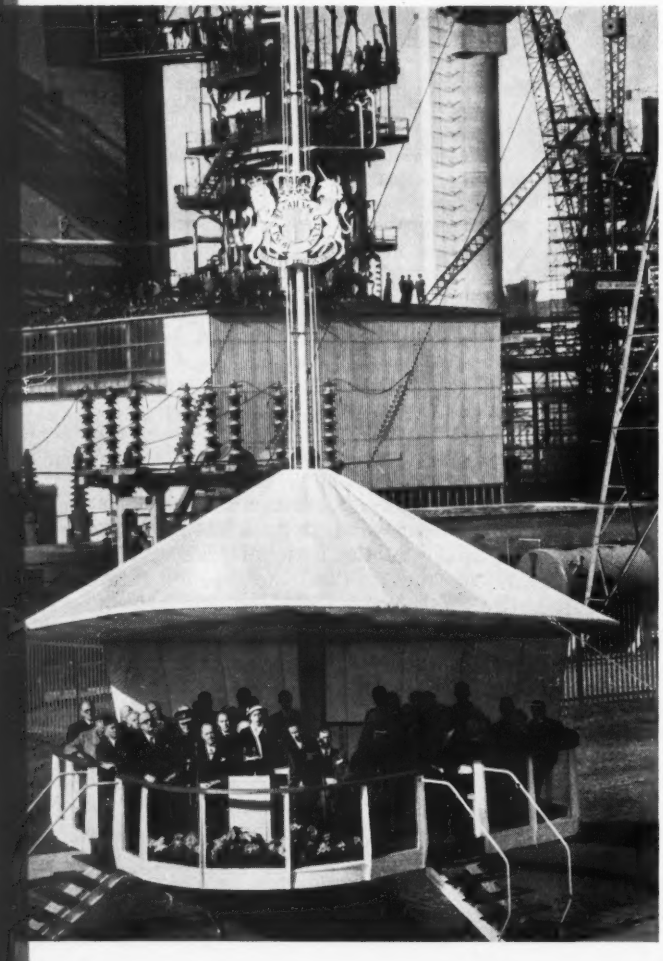
That sense has been dramatically restored by the advent of the atomic age. We have been made vividly aware that the physical world, in which the great adventure of human life is lived, is of a complexity which must inspire in us a sense of awe. More than that; in the atom, man has discovered vast powers and ways to control them, and their tremendous possibilities for good or evil must fill us with a sense of humility. As new fields open before us, we become conscious that a grave responsibility is placed upon all of us to see that man adds as much to his stature by the application of this new power as he has by its discovery.

Future generations will judge us, above all else, by the way in which we use these limitless opportunities which Providence has given us and to which we have unlocked the door. They offer us, as we have heard today, a vital and timely addition to the industrial resources of our nation and to our material welfare. But, above all, we have something new to offer to the peoples of the undeveloped and less fortunate areas of the world, who will continue to look to us for assistance and example as they have done in the past.

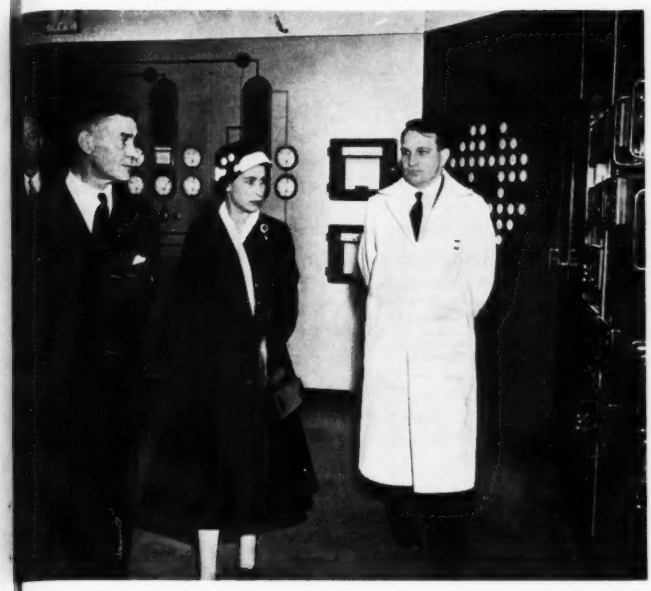
That, to me, is the real importance of today's ceremony. For centuries past visionary ideals and practical methods which have gone from our shores have opened up new ways of thought and modes of life for people in all parts of the world. It may well prove to have been among the greatest of our contributions to human welfare that we led the way in demonstrating the peaceful uses of this new source of power.

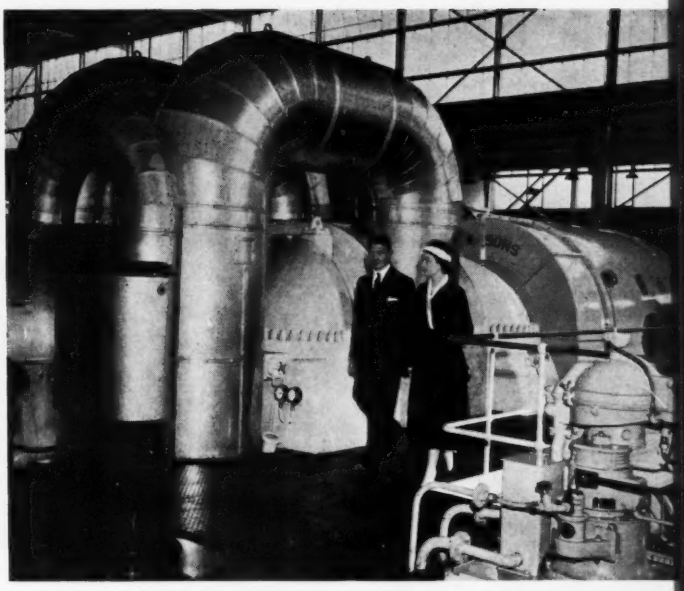
I congratulate all those who have shared in this fine project—both those who conceived and planned the industrial application of atomic energy in this way, and those who have worked to see their plans fulfilled. And I hope this occasion will be an inspiration and encouragement to all who will continue this exciting enterprise, here and elsewhere.

It is with pride that I now open Calder Hall, Britain's first atomic power station.



The opening ceremony. The Queen makes her speech from the Royal dais.





Conducted by Mr. H. G. Davey, works general manager, Northern Area, A.E.A., the Queen toured the Calder Hall plant before the opening. (Left) In the control room. (Right) In the turbine hall.

Speech by Sir Edwin Plowden, K.C.B., K.B.E.

Chairman, United Kingdom Atomic Energy Authority

YOUR Majesty, may I on behalf of the Atomic Energy Authority, welcome you to Calder Hall.

We greatly appreciate the honour you have done us in consenting to open this station. We are proud of this power station. Although the day will come when we shall look back on it with the feelings which we now have for the first steam engine and for the first aircraft, future achievements will not detract from the importance of this first great practical step forward.

The pace of advance has been rapid. In 1937 Lord Rutherford himself said: "The outlook for gaining useful energy by artificial processes of transformation does not look promising". That was less than 20 years ago. Those 20 years have seen the Second World War and all the needs of reconstruction.

But, in spite of their other pre-occupations, British scientists and engineers under the leadership of Sir John Cockcroft and Sir Christopher Hinton have moved forward and changed that unpromising outlook into the industrial-sized power station which stands before us.

I should like to express the gratitude of all of us in the Authority for the help that we have had from British industry. As this power station has been designed and built, we have made many demands, and British industry has responded with skill and success to them all. From now on industry will play an even larger part. The Atomic Energy Authority will remain a pioneering body, and it is industry that will be responsible for developing and building atomic power stations for the electricity authorities at home and abroad.

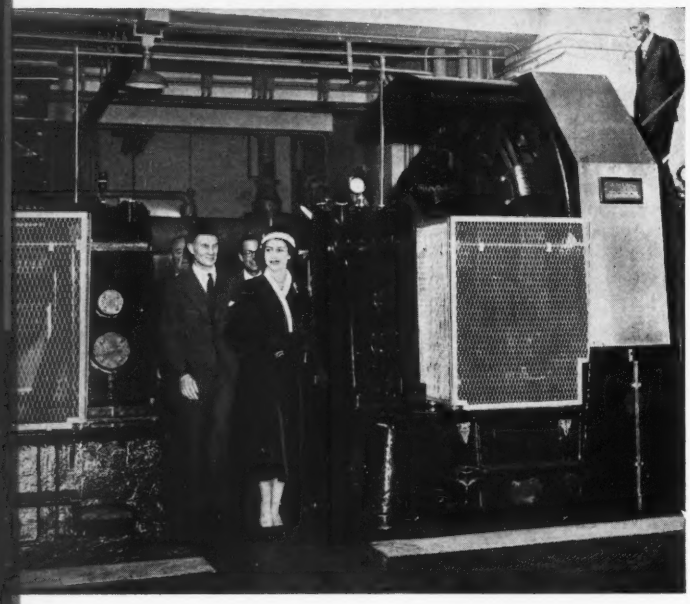
For the last 18 months four groups of firms have been studying Calder Hall and preparing themselves to build power stations of the same type. They have already submitted tenders to the Central Electricity Authority for the first two stations to be built. The building of these stations will begin next year. We believe that the experience gained in building Calder Hall will prove of great benefit and that these new stations will produce electricity at a price comparable with the most modern type of coal-fired stations in this country.

To meet the growing demands of industry, the Authority's reactor school at Harwell has been expanded and in about a month's time we shall be opening here at Calder a reactor operations school which will eventually take from this country and abroad about 100 students a year. Nuclear power development, with its exacting technical requirements, has confronted industry with new problems in engineering, metallurgy and in other fields. It will do this increasingly. The lessons learnt in solving these problems are often of direct value in other parts of the engineering and chemical industries. Even when they are not, the very fact that there are these problems, and that they are being solved, adds drive, confidence and momentum to the whole process of technical advance.

The Lord Privy Seal has spoken of the nuclear power programme and of its importance to the United Kingdom. In this country we must live by our brains and by our skills. Today we see the birth of a new industry. If we follow up this first success with vigour and determination, our country and the world will be assured of a source of power which will be inexhaustible for many generations to come. Calder Hall is a supreme example of what can be done by the skills of scientists, engineers and workpeople acting together. It is, I believe, a good augury for the future.

Your Majesty, on the control desk before you is a lever; when it is pulled it will switch electric power in the turbine house of the Calder Hall station into the national grid of the Central Electricity Authority.

I now ask Your Majesty to open this station.



(Upper) On the charge floor.
(Lower) In the blower house.

Presentations

The Rt. Hon. R. A. Butler, P.C., C.H., *Lord Privy Seal.*
Sir Edwin Plowden, K.C.B., K.B.E., *chairman, United Kingdom Atomic Energy Authority.*
Sir John Cockcroft, K.C.B., C.B.E., F.R.S., *members of U.K.A.E.A. for Scientific Research: director, Atomic Energy Research Establishment, Harwell.*
Sir Christopher Hinton, F.R.S., *member of U.K.A.E.A. for Engineering and Production, managing director, Industrial Group.*
Lady Hinton.
Sir Donald Perrott, K.B.E., *member of U.K.A.E.A. for Finance and Administration*
Mr. W. Strath, C.B., *member of U.K.A.E.A. for External Relations and Commercial Policy.*
Sir Luke Fawcett, C.B.E., *part-time member, U.K.A.E.A.*
Mr. C. F. Kearton, C.B.E., *part-time member, U.K.A.E.A.*
Sir Rowland Smith, *part-time member, U.K.A.E.A.*
Sir Ivan Stedeford, K.B.E., *part-time member, U.K.A.E.A.*
Mr. D. E. H. Peirson, *secretary, U.K.A.E.A.*
Mr. W. L. Owen, C.B.E., *director of Engineering, Industrial Group.*
Mrs. Owen.
Mr. D. A. Shirlaw, C.B.E., *lately director of Administration, Industrial Group.*
Mr. L. Rotherham, *director, Research and Development, Industrial Group.*
Mr. K. B. Ross, O.B.E., *director, Operations, Industrial Group.*
Mr. D. R. Newman, *director, Accounts and Stores, Industrial Group.*
Mr. J. C. C. Stewart, *director of Technical Policy, Industrial Group.*
Mr. D. S. Mitchell, *director, Administration, Industrial Group.*
Mr. D. W. Cole, C.B.E., *deputy director, Operations, Industrial Group.*
Mr. J. B. W. Cunningham, *deputy director, Civil Reactors, Industrial Group.*
Mr. P. T. Fletcher, *deputy director, Engineering, Industrial Group.*
Mr. T. L. Viney, *deputy director, Works and Buildings, Industrial Group.*
Mr. H. G. Davey, O.B.E., *works general manager, Northern Area.*
Mrs. Davey.
Mr. R. V. Moore, G.C., *assistant director, Civil Reactors, Industrial Group.*
Mr. A. Young, *resident engineer, Calder Hall.*
Mr. K. L. Stretch, *works manager, Calder Hall.*
Sir Robert Chance, *H.M. Lieutenant for the County of Cumberland.*
Lady Chance.
The Rt. Hon. the Lord Adams, O.B.E., *West Cumberland Industrial Development Co. Ltd.*
Mr. F. Anderson, M.P., *Member for Whitehaven.*
The Rt. Rev. T. Bloomer D.D., *Lord Bishop of Carlisle.*
Prof. Niels Bohr, *chairman, Danish A.E.C.*
The Hon. Winthrop G. Brown, *Minister of Economic Affairs, U.S. Embassy, representing U.S.A.E.C.*
The Rt. Hon. the Lord Citrine, K.B.E., *chairman, Central Electricity Authority.*
Mr. J. Cook, *chairman, Ennerdale Rural District Council.*
Sir Claude Gibb, O.B.E., F.R.S., *C. A. Parsons and Co. Ltd.*
M. P. Guillaumat, *Administrator General, French A.E.C.*
Sir Kenneth Hague, *Babcock and Wilcox Ltd.*
Mr. A. J. Hill, *Taylor Woodrow Construction Ltd.*
The Rt. Hon. Aubrey Jones, M.P. *Minister of Fuel and Power.*
The Rt. Hon. the Viscount Portal, K.G., K.C.B., O.M.
The Rt. Hon. the Lord Rea, O.B.E., *Deputy-Lieutenant of Cumberland.*
Alderman C. H. Roberts, *chairman, Cumberland County Council.*
The Rt. Hon. Lord Silkin.
Lt.-Colonel J. E. Spedding, O.B.E., *High Sheriff of Cumberland.*
Mr. C. M. Spielman, *Whessoe Ltd.*
Herr Minister F. J. Strauss, *Federal Minister for Atomic Affairs, West Germany.*
Mr. G. N. C. Swift, *Clerk to the Lieutenancy and to the County Council of Cumberland.*
Academician A. V. Topchiev, *General Scientific Secretary, U.S.S.R. Academy of Sciences.*
Mr. Harold S. Vance, *United States of America Atomic Energy Commission.*
The Rt. Hon. the Viscount Waverley, G.C.B., G.C.S.I., G.C.I.E., F.R.S.
Major F. G. Wilson, *chairman, Millom Rural District Council.*

(Right) Distinguished visitors and representatives of the major contractors and the A.E.A. engaged in the design and erection of Calder Hall are presented. In the background, on the roof of the administration building, can be seen the watt-hour meter which recorded the passing of electricity into the grid.

Nuclear Energy and the Export Market

by
M. D. WOOD, B.A., Ph.D., B.Sc., (Eng.), Wh.S.Sc.
Nuclear Project Engineer, Ruston and Hornsby Ltd.

The optimum type of reactor for a particular generating system will depend largely on the power requirement. Before undertaking a development programme to produce export units, it is necessary that a close examination of the future market be made. Due allowance must be made for changes in demand during the development period.

BOTH the Geneva Conference and the Fifth World Power Conference stressed that the under-developed countries have neither the technology nor the resources to build their own reactor power stations, but are in urgent need of electrical power to develop their growing industries.

For tne past 18 months Ruston and Hornsby Ltd. have concentrated their attention on the possibility of exporting small power plants to fulfil this requirement. With its experience of the export of industrial Diesel engines and gas turbines, the company recognized that the first tentative inquiry, received in mid-1955, for a reactor power plant with a 10-MW output would be characteristic of future demands. At this time the company's effort in the nuclear field had been limited to the training of personnel. However, encouraged by this enquiry, a survey was undertaken in order to determine the extent of the demand for nuclear power and the size and type of plant that would be required. The survey was submitted to the U.K.A.E.A. during the spring of 1956.

Reactor Type and Supply Date

Sales staff experience indicated that 1 to 10 MW of electricity generating capacity was the probable order of magnitude of power output of nuclear stations required for the export market. This immediately showed that a small reactor using enriched fuel would be required. Supplies of enriched fuel would be limited in the U.K. until at least 1965, and it was therefore decided to investigate the probable requirements for units which might be marketed in the period 1965-75. This would leave a reasonable period (nine years) for the design, construction and prototype development of the special-purpose reactor and prime mover required for the project (not excessively long—the interval between the conception of a new Diesel engine and the sale of the first production model may be as long as seven years). It was further assumed, based on information from the Geneva Conference, that the "doubling time" of the required output of representative overseas power stations would be approximately ten years.

The Present Export Position

It was first necessary to assess the current rate of exports to determine whether the effort involved in developing an export reactor would be worth while in terms of the possible overseas currency return. Fig. 1 shows the available data on Diesel-engine exports from the United Kingdom since 1948. The engines have been divided into two size ranges:

(a) 300-1,500 b.h.p. per engine;
and (b) above 1,500 b.h.p. per engine.

Whilst a proportion of the Diesel engines in the 300-1,500 b.h.p. range are installed individually or in small power plants, others go to centralized power stations which, in some cases, have installed capacities as high as 10 MW. Therefore, on the assumption that 1 MW is the smallest size that is likely to be of interest in the nuclear export market, category (a) represents engines which come into this range when several units are installed in the same power house, and category (b) represents the range where even a single unit would be of interest. (It should be noted that marine propulsion and auxiliary units have been omitted from the analysis, although both these types of application have great long-term potentialities for nuclear power.)

The upper curve shows the total United Kingdom production of category (a) engines since 1948, and the curve immediately beneath shows the proportion of this production which has been exported. Apart from the recession in trade in 1953, it may be seen that the export value of this range of engines has been approximately constant at a value of 200 MW per annum since 1952.

The next two curves on Fig. 1 show the U.K. production and export figures for category (b) engines. A steady rise of production since 1950 leads to a peak of 180,000 b.h.p. during 1954. If this figure was made up by the export of 1,500-b.h.p. engines, it would represent 120 power stations, each of over 1-MW rating.

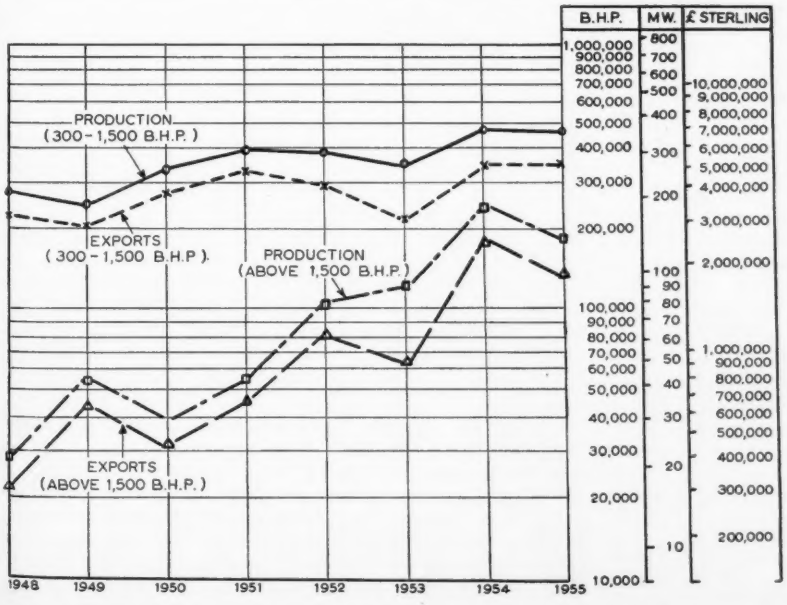
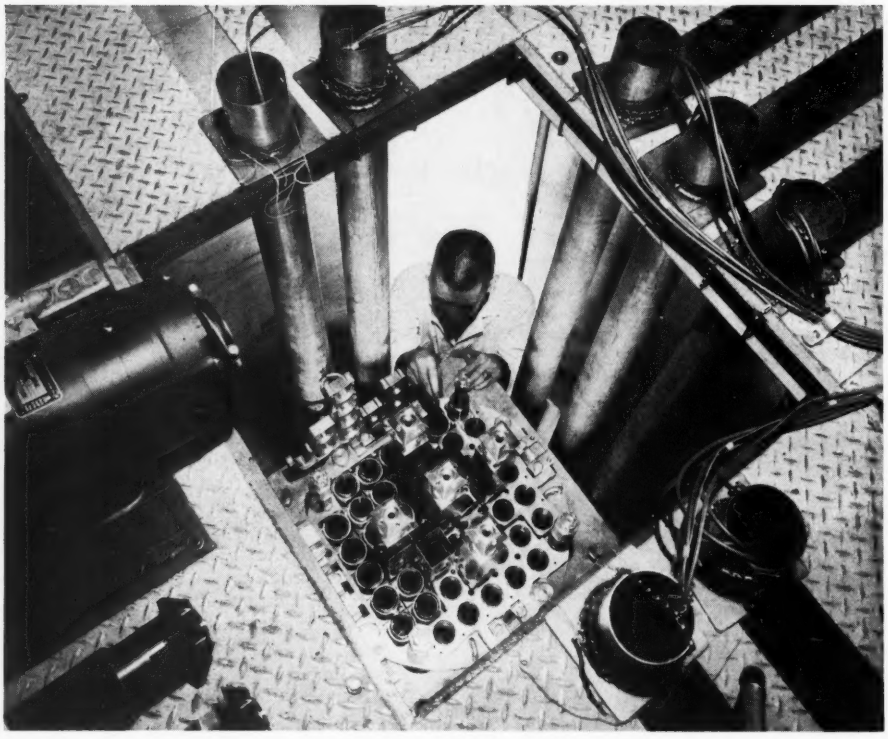
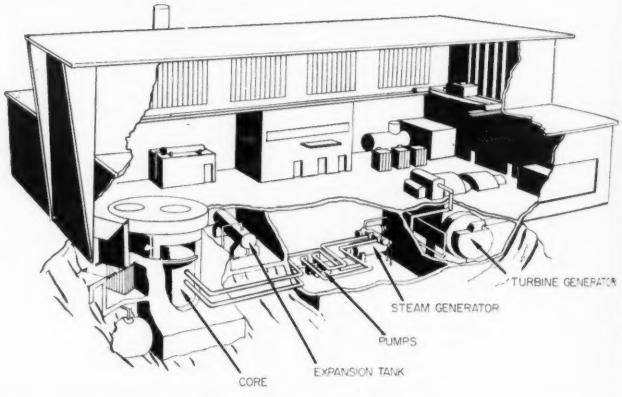


Fig. 1. Diesel-engine exports from 1948-1955, showing equivalent generating capacity and value.



(Left) Looking down on the APPR, the packaged pressurized-water reactor under development by Alco Products Inc.



(Below) Proposed layout of an organic - moderated reactor power station under development by Atomics International for installation in a South American country.

In addition, the export of steam turbines of all sizes up to 10 MW amounts to some 75-100 MW per annum. Many of these units would be in the 5-MW size range.

The set-back in dispatches of category (b) engines in 1955 is very significant. It shows the first effects of the return of German competition to the export market, and underlines the need for this country to concentrate on new products. The drop in exports in 1955 emphasizes that economic stability can only be achieved by a balance between the demands of the home and export markets. A balanced approach will, it is hoped, help to prevent the occurrence of a situation in which nuclear power is made available for the home industries to produce goods for which there is no sale in overseas markets.

Prospects for Future Exports

Fig. 1 shows that the present combined rate of export of category (a) and (b) Diesel engines (~250 MW per annum) is comparable with the average rate of commissioning of the nuclear power stations originally envisaged in the "Programme of Nuclear Power" (~2,000 MW in ten years). It would therefore seem that the export market could readily absorb the relatively small proportion of the U.K. nuclear effort that may be diverted from the main programme for the Central Electricity Authority. Possible supply and probable demand appear to be well balanced. However, before drawing firm conclusions from the overall figures it is necessary to analyse the possible markets in detail.

A reactor offers at least one great advantage over other sources of heat. The fuel need only be replenished at infrequent intervals, and the replenishment is light and compact. To make the best use of this, the most obvious markets would be in countries where fossil fuel must be imported or transported for long distances overland, and where power costs are already high by United Kingdom standards.

South America

Uruguay is an example of the demand in the South American continent. The present scheme to install a second 100-MW hydro-electric plant represents the limit of the economically available water power. It is anticipated that this station will cover requirements for the next seven years, but after this the country will need to turn to nuclear power or, as a poor alternative, import large quantities of fossil fuel. In the north the population centres are scattered and are now served by 1 to 6-MW stations. With transmission line installation costs of £4,000 per mile, it would not appear economic to build a large central station of the 100-MW category for future expansion. With a power consumption doubling time of about ten years, the demand in 1965 could be satisfied by the installation of several local 10-MW nuclear generating stations.

Whilst Argentina and Venezuela have oil resources, other South American countries must import fuel, and may be regarded as potential markets. Transporting fuel oil to inland power stations can have a significant effect on generating costs. In a particular installation in central South America, fuel costs are trebled by delivery charges. A nuclear power reactor would be very attractive in this type of installation.

Already American and Foreign Power has placed contracts for the installation of two 10-MW stations in South America. The first of these is with Babcock and Wilcox of America for

a station at Sao Paulo in Brazil incorporating a liquid-metal-fuelled reactor, and the second for a boiling-water reactor station with General Electric. In addition, Cuba is to have a 10-MW station based on an organic-moderated reactor to be built by Atomics International. None of these is near even the completed design stage, but each is being investigated with American and Foreign Power as a firm customer.

Canada

The wood-pulping mills to be developed in outlying parts of Northern Canada are further examples of the possible applications of reactor power generation. In spite of the ready availability of waste wood, applications of this kind have been suggested for further economic study. In this type of plant both power and process heat are required, and this has been shown to be an ideal application of the open-cycle gas turbine. The average Canadian paper mill (there are 120 in all) requires 30-40 MW of electrical power and operates at high load factor. In spite of this apparent demand for large generation capacity, Dr. J. Davis, of the Department of Trade and Commerce, Ottawa, considers that the greatest demand for power in the Canadian North will be in 2 to 3-MW sizes. Other authorities in Canada have stated that they must have package reactors in five or six years and mean to get them. To allow for the increase of power consumption during the period of reactor development, the design capacity should be increased from the stated required value of 2-3 MW to about 5 MW.

Scandinavia

The wood-pulp industries in Scandinavia offer the same possibilities for the sale of nuclear power plant as Northern Canada. The Norwegians have, in fact, already started to develop a reactor to produce 10 MW of process heat for this industry.

The Mining Districts of Central and East Africa

Installations in this area which are remote from sources of hydro-electric power consist, in general, of Diesel generating plant. The transport costs of imported conventional fuels result in high-cost electrical power, and the possibility of refuelling at infrequent intervals would make a nuclear power station extremely attractive. Individual diamond mines are already equipped with Diesel generating stations of between 6 and 9 MW total capacity. Power costs are approximately 2.0 pence per unit, showing that generation at up to three times the cost of electricity from the Calder Hall type of station would be highly competitive. Power consumption is not likely to rise rapidly in this type of mine due to external restrictions on production and it would appear likely that a 10-MW power reactor would be suitable for supply in 1965. Preliminary cost figures from the American APPR (*Nuclear Engineering*, July, 1956) indicate that it may be possible to produce electricity from a 10-MW unit at an all-in cost of 1.5 pence per unit.

India and Pakistan

The rapid industrialization of India shows a potential market for community-serving 5-MW power stations. India's reserves of unexploited hydro-electric power will be sufficient to delay the change to nuclear plant in the largest stations for some 25 years. However, the demand for smaller units of generating capacity in isolated areas could be supplied by the 5-MW sets.

The demand is similar in Pakistan, but because of the smaller hydro-electric potential, the need for both large and small reactors is much greater. It has been announced recently that the estimated power deficiency in Pakistan will be 200 MW by 1965, and that steps are being taken to explore the possibilities of using nuclear energy to bridge the gap. Already the Atomic Energy Council has approved in principle the construction of a nuclear power station in the easterly region.

In both countries, the availability of capital would bias the selection of imported reactors towards the smaller sizes.

Australia

This market may be supplied directly by the Australian Atomic Energy Commission. However, it is interesting to note that the work of the Commission will be concentrated on small power stations. The Australian Minister of Supply, Mr. Beale, recently announced that the Lucas Heights Nuclear Research Establishment would be used for power reactor materials testing, and that the emphasis would be on "generators producing from 5 to 10 MW, which would be invaluable for the development of inland Australia". (See also *Nuclear Engineering*, August, 1956.)

Typical Inquiries

The following list of inquiries which have been made to Ruston and Hornsby Ltd. within the past few years also indicates the size of power plant that will be required to exploit the demand in the export market.

Guernsey	2 MW
Chile	2 MW
Nigeria	2 MW
Lebanon	2-5 MW
Jersey	1.5 MW
Costa Rica	3 MW
Peru	4 MW
Indonesia	3 MW
Australia	4 MW

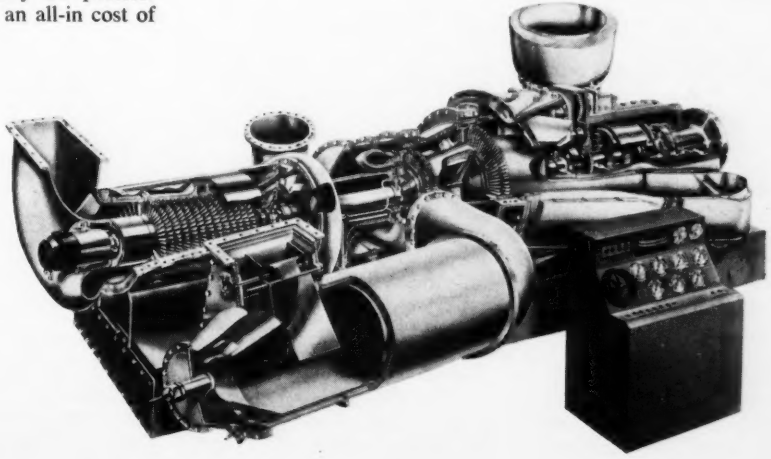
It must be stressed again that an attempt is being made to predict demand in 1965. These inquiries should, therefore, be scaled up by 50 to 100% to take account of the estimated rise in consumption in the next decade.

The preceding paragraphs indicate that the demand for power plants in 1965 falls into two distinct categories:

(i) for 5-MW units;

(ii) for 10-MW units.

An analysis of some 40 overseas Diesel stations shows that



The Ruston and Hornsby gas turbine, Type T.A., with a maximum rating of 1,410 b.h.p.

average cost per kWh sent out during 1953 was 1.88 pence (including a 5% capital charge). The average station size was 4.25 MW and the average load factor 27.5%. It would be unrealistic to imagine that nuclear plant could compete with Diesel power at these low load factors (~30%). However, it is unlikely that a reactor would be installed as the only power-producing unit in any one station. It is more likely to form part of an integrated system of fairly high load factor in which the nuclear plant would supply the base load and Diesel engines would be used for stand-by and peak load.

Recent estimates made by this company indicate that the cost of electricity generated by a 5-MW nuclear station running at 80% load factor could be reduced to 2-2.5 pence per unit, provided that the reactor fulfilled certain, quite stringent, conditions. The company has already supplied generating units to a remote mining station where the average load is 85% of the peak load of 7.5 MW and where generation costs are above 2.0 pence per unit. The number of stations of this type is not large, but may be expected to increase as the search widens for the new raw materials.

Choice of Prime Mover

The successful prime mover for the export market must be reliable, easy to control, vibration-free (thus requiring the simplest foundations), and have either high efficiency or a high heat utilization. In many cases it is an additional advantage if the cooling-water requirements are low.

The choice of prime mover to be coupled to a reactor to give a power output of 5-10 MW is limited to the steam or gas turbine. Both types of prime mover give long life and reliability, but the open-cycle gas turbine is able to respond to rapid load changes (even instantaneous acceptance and shedding of full normal output) and requires no cooling water.

Provided that the reactor system offers a sufficiently high temperature to enable a reasonable efficiency to be achieved, the gas turbine would be an automatic choice.

Advantages of Exporting Small Power Reactors

The advantages are not limited to the direct currency return from the exported machinery, although this would make an increasing contribution to the national income. In selling nuclear plant it will be necessary to guarantee the future supply of enriched fuel to the customer. This will, in effect, provide a regular overseas currency return throughout the life of the unit. The export of nuclear power therefore shows a great advantage over the export of Diesel power. The cost of the first year's fuel-oil supply to a new Diesel unit may exceed the cost of the engine which uses it. The U.K. would only receive a small financial return for arranging the supply of the Diesel oil, but, in the case of an alternative nuclear unit, would benefit to the full extent of the cost of the fissile material which is essentially "home produced".

The second advantage of exporting nuclear power is less easy to define, but will, in the long term, be as important as direct financial returns. Should the United Kingdom fail to develop a small export reactor, the demand will, in all probability, be satisfied by the Americans, who have a comparative abundance of enriched fuel and are already developing plant in the 10-MW range. This would permit them to penetrate into export markets which, until now, have been regarded as predominantly British. As a result of this infiltration, there might be a tendency to argue that since the power supply units were manufactured in the United States it would be logical to standardize on "all-American" equipment. The effects of such a policy would have a significant influence on the level of future U.K. exports.

The announcement that the U.K.A.E.A. is prepared to use Stage 3 prototype reactors to investigate the economics of 10-MW power stations, and that the necessary enriched fuel will be made available for export should these units show promise, will have far-reaching consequences.

L'Energie Nucléaire et le marché d'exportation

L'article est un résumé d'une enquête effectuée par Ruston and Hornsby Ltd., pour la prospection du marché pour les petites génératrices à réacteur. En se basant sur la supposition que les approvisionnements en combustible enrichi et la période de développement empêcheraient l'établissement d'un marché avant 1965, les besoins probables ont fait l'objet d'une enquête couvrant la période de 1965 à 1975. Comme base d'enquête on cite des chiffres de l'exportation des moteurs diesel depuis 19.8, lesquels, d'après les conclusions du rapport, continueront à peu près au même niveau, mais seront en dernier ressort augmentés par les petites génératrices à réacteur. Des exemples sont donnés des besoins en Amérique du Sud, au Canada, en Scandinavie, aux régions minières de l'Afrique Centrale et de l'Est et aux Indes et Pakistan. L'Australie est aussi comprise dans l'enquête et des demandes qui ont été en fait reçues de certains pays sont énumérées. Le rapport conclue que la demande de génératrices en 1965 tombera en deux catégories distinctes, c'est-à-dire les groupes de 5 MW et 10 MW. Ces groupes ne seraient pas à même de faire concurrence aux facteurs de charge obtenu normalement pour la génération par diesel, mais peuvent assurer une fourniture utile de charge de base pour les groupes intégrés. Un coût de génération de 2d. par unité semblerait faisable dans ces circonstances.

Kernenergie und Exportmarkt

Der Artikel berichtet zusammenfassend über eine Untersuchung, die von der Firma Ruston and Hornsby Ltd. zur Ermittlung der Marktlage für kleine Reaktorkraftwerke durchgeführt wurde. Unter der Annahmen, dass die Versorgungslage für angereicherte Brenstoffe und die technische Entwicklung den Aufbau eines Exportmarktes erst nach 1956 ermöglichen werden, ist der wahrscheinliche Bedarf für die Periode 1965 bis 1975 aufgestellt worden. Als Grundlage für die Untersuchung dienten Angaben über den Export von Dieselmotoren seit 1948, wobei der Bericht annimmt, dass dieser Exportumfang vermutlich aufrechterhalten aber schliesslich von den kleinen Atomkraftwerken ergänzt werden wird. Der Artikel bringt Beispiele des Bedarfs in Südamerika, Kanada, Skandinavien, den Minengegenden von Zentral- und Ostafrika und in Indien und Pakistan. Australien ist ebenfalls erfasst, und es werden die bereits eingegangenen Anfragen aus den verschiedenen Ländern aufgezählt. Der Bericht kommt zu dem Schluss, dass der Bedarf an Kraftstationen im Jahre 1965 sich in zwei Kategorien aufteilen wird, d.h. solche für 5 MW und 10 MW Leistung. Diese können allerdings kaum bei den für normale Dieselgeneratoranlagen geltenden Lastfaktoren konkurrenzfähig sein, sie können aber für Lieferung der Grundleistung der bereits vorhandenen Werke in Frage kommen. Stromkosten von 2 Pance (etwa 10 Pfennig) je KW scheinen unter diesen Umständen tragbar zu sein.

La Energia Nuclear y el Mercado de Exportación

El articulo es un resumen de una investigación llevada a cabo por Ruston & Hornsby Ltd., para determinar el mercado que exista para pequeñas centrales generadoras a reactor. Sobre la base de que los abastecimientos de combustible enriquecido y el tiempo de evolución evitarían el establecimiento de un mercado antes de 1965, las posibles necesidades han sido investigadas para cubrir el período 1965-1975. Como una base para la investigación se citan las cifras de la exportación de motores diesel desde 1948, cuya exportación, según el informe, continuará probablemente sobre aproximadamente el mismo nivel pero a las largas será suplementada por pequeñas centrales de energia a reactor. Se citan ejemplos de las necesidades en Sud América, el Canadá, los países escandinavos, los distritos mineros de Africa del Centro y del Este, y en la India y Pakistán. Australia también ha sido incluida en la investigación, y hay lista de solicitudes efectivamente recibidas de diversos países individuales. El informe llega a la conclusión que la demanda para centrales de energía en 1965 caerá dentro de dos categorías distintas, v.g., unidades de 5 MW y de 10 MW. Estas unidades no podrían competir con los factores de carga que, como promedio, se obtienen para generación con motores diesel, pero pueden formar un abastecimiento útil de carga de base para unidades integradas. Parece que en estas circunstancias un costo de generación de 2d. por unidad sería factible.

Canadian Review

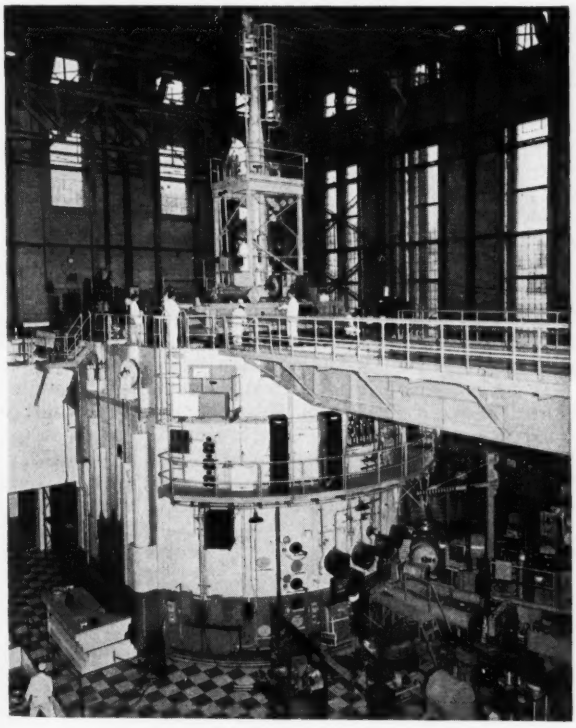
The A.E.C.L. Annual Report

STEADY progress seems to be the keynote of the annual report issued by Atomic Energy of Canada Ltd., covering their operations from April 1, 1955, to March 31, 1956.

Research and Development

A programme of fundamental research, as the report points out, is almost impossible either to define or to describe in detail, and reference is made to a separate list of information obtainable from the Scientific Document Distribution Office. On the question of testing of fuel systems and components emphasis is laid on the unique facilities provided by the high flux and ample irradiation space of the NRX reactor, which has been employed on fuel elements for the PWR reactor of the U.S.A.E.C. The NRU reactor now nearing completion will, of course, have a higher flux and larger irradiation space than the NRX and will provide improved facilities.

Reference is made to design and feasibility studies under way on a large power reactor *(previously reported as* 100-200 *MW)* and the policy to be pursued regarding collaboration with manufacturers on detailed studies. Other design and feasibility studies under consideration include two types of industrial reactors, a dual-purpose unit providing power and process steam for the pulp and paper industry and a small reactor for power and heating in remote areas of the North where conventional fuels are unduly expensive.

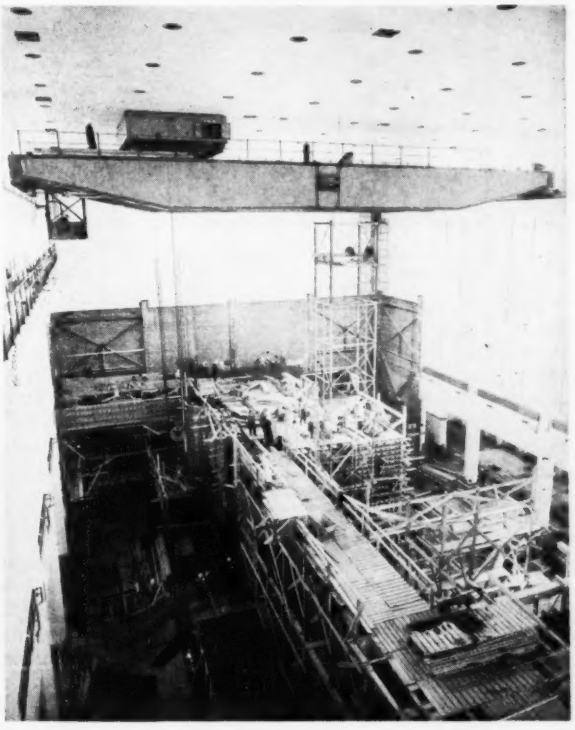


General view of the original NRX reactor.

Reactors Under Construction

Two reactors are in course of construction, the NRU, previously referred to, and the NPD.

Site work on the NRU has been satisfactory but there have been unexpected delays in deliveries of certain components, although it is still expected to be ready for operation by the end of 1956. A natural uranium reactor, with heavy water as moderator and coolant, the NRU has a thermal rating of 200 MW—five times that of the NRX. A triple-purpose unit, it will produce substantial quantities of plutonium, and large quantities of isotopes, notably cobalt-60, in addition to its research and experimental facilities.

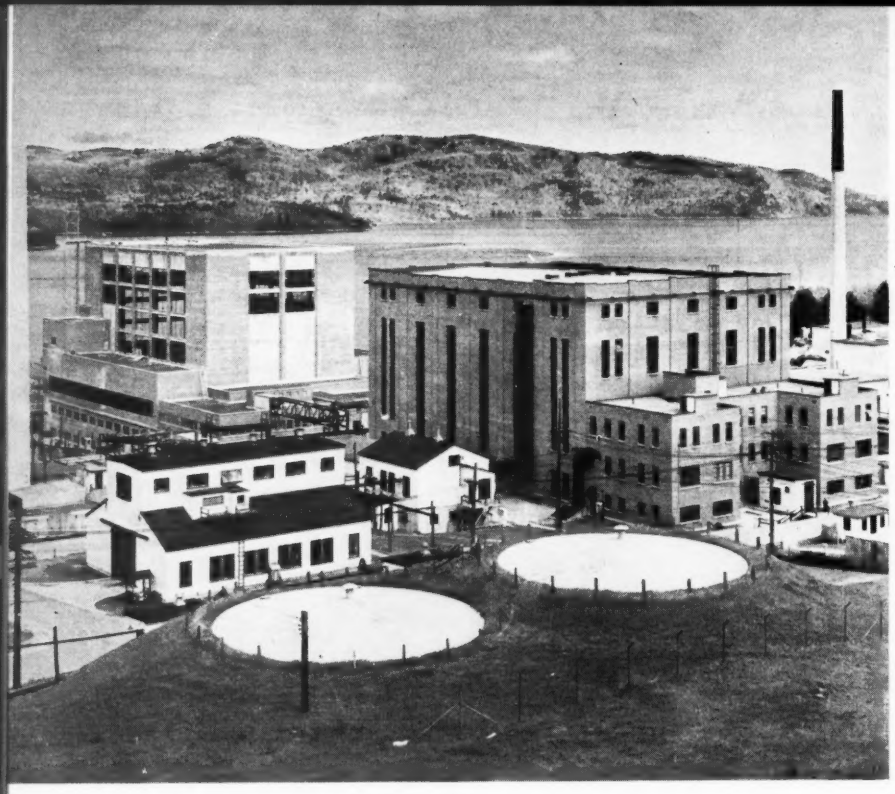


General view of the NRU reactor under construction.

The NPD, which is being built in association with the Hydro-electric Commission of Ontario and the Canadian G.E., is located near the Des Joachims hydro power station on the Ottawa River about 20 miles upstream from Chalk River. It is a pressurized heavy-water reactor using natural uranium, and is to provide 20 MW electrical output. Its estimated cost is $14,500,000.

Co-operation with Industry

A.E.C.L. policy has always been to provide the maximum possible participation in the power reactor development programme, for both utilities and manufacturers. Utility participation is two-fold, the utilities being represented on the Advisory Committee on Atomic Power, and, through



General view of Chalk River, showing the three reactor buildings. "Zeep", in the left foreground, is a low-power reactor made critical in 1945, the first to operate outside the United States. The NRX building is the large building on the right; the NRU is in the background.

recruitment of utility personnel for the Nuclear Power Branch at Chalk River; thus enabling utilities to assess the economic importance of nuclear power to their own needs, and helping A.E.C.L. to "tailor" the Chalk River programme to suit. The Nuclear Power Branch was originally established to undertake the preliminary design study for NPD and is now engaged in a similar study for the large power reactor.

Co-operation with the manufacturers involves the supply of a considerable amount of information before the manufacturer can assess the extent of his participation in the programme. In addition to published information available, A.E.C.L. hold many conferences at Chalk River with individual manufacturers and with groups. A valuable innovation has been the setting-up of an Office of Industrial Assistance to supply information and deal with enquiries, and to arrange conferences.

More than 100 Canadian manufacturing companies have been engaged in components for the NRU reactor in addition to the NPD, and contracts have also been awarded for the design and construction of a swimming pool research reactor and a loop for the NRU.

The establishment of facilities for design, development and fabrication of fuel elements is being actively encouraged.

Commercial Products

Isotope shipments by this division during the year increased by some 400, to a total of 1,500, the increase in radioactivity being from 11,000 c to 50,000 c, a high proportion being accounted for by cobalt-60 for use in therapy units, of which 44 have been installed in various parts of the world, orders being in hand for a further thirty. A lower-cost model of cobalt therapy unit, the "Theratron Junior," is now being marketed to supplement the two previously available. Design work on an industrial radiography unit is well advanced and plans are under way on two further therapy units, one of which will use caesium-137. Export sales of isotopes account for 66% of the gross revenue.

International Co-operation

A.E.C.L. was responsible for organizing the Canadian delegation to Geneva in August last; 36 members made up the team and 13 papers were presented. The Company also acted in an advisory capacity to the Canadian delegation to the Washington 12-power conference in March.

The excellent relations between the Company and the U.K.A.E.A. are mentioned in an account of the annual U.K.-Canada technical conference at Chalk River in October, 1955. Co-operation between Canada and the U.S.A. on the peaceful uses of atomic energy has been extended by a bilateral agreement in June, 1955. Co-operative arrangements with other countries included the exchange of technical reports with scientific societies all over the world as it has done for some years. Technical teams from Australia, Belgium, Brazil, Burma, Egypt, France, India, Japan, New Zealand, Norway, Peru, Portugal, Southern Rhodesia, Sweden, and Switzerland visited Chalk River during the year.

Finance

Operations for the financial year required a total of $32,452,212, of which the major portion was obtained from Government appropriations although some $2 million was produced from operation of facilities and rental and sale of products. Government appropriations are divided into four categories: $10,964,046 for research operating expenditures; $7,662,009 for research capital; $10,156,174 for production capital (i.e., projects that are expected to have an earning capacity) and $1,560,000 for production working capital (i.e., expansion in raw material stocks). Capital stock is issued for the two latter categories.

Administration and Personnel

Deep River village, established for the Chalk River project staff, has now been transferred to normal municipal administration in view of its growing size.

At the end of the period under review, the Company employed 2,199, 1,129 being salaried staff (359 of whom were university graduates) and 1,070 hourly rated workers.

Accident frequency was 1.14 per million hours worked. Over a period of 261 days (June-February), there was no lost time accident. There was no lost time due to exposure to radioactivity.

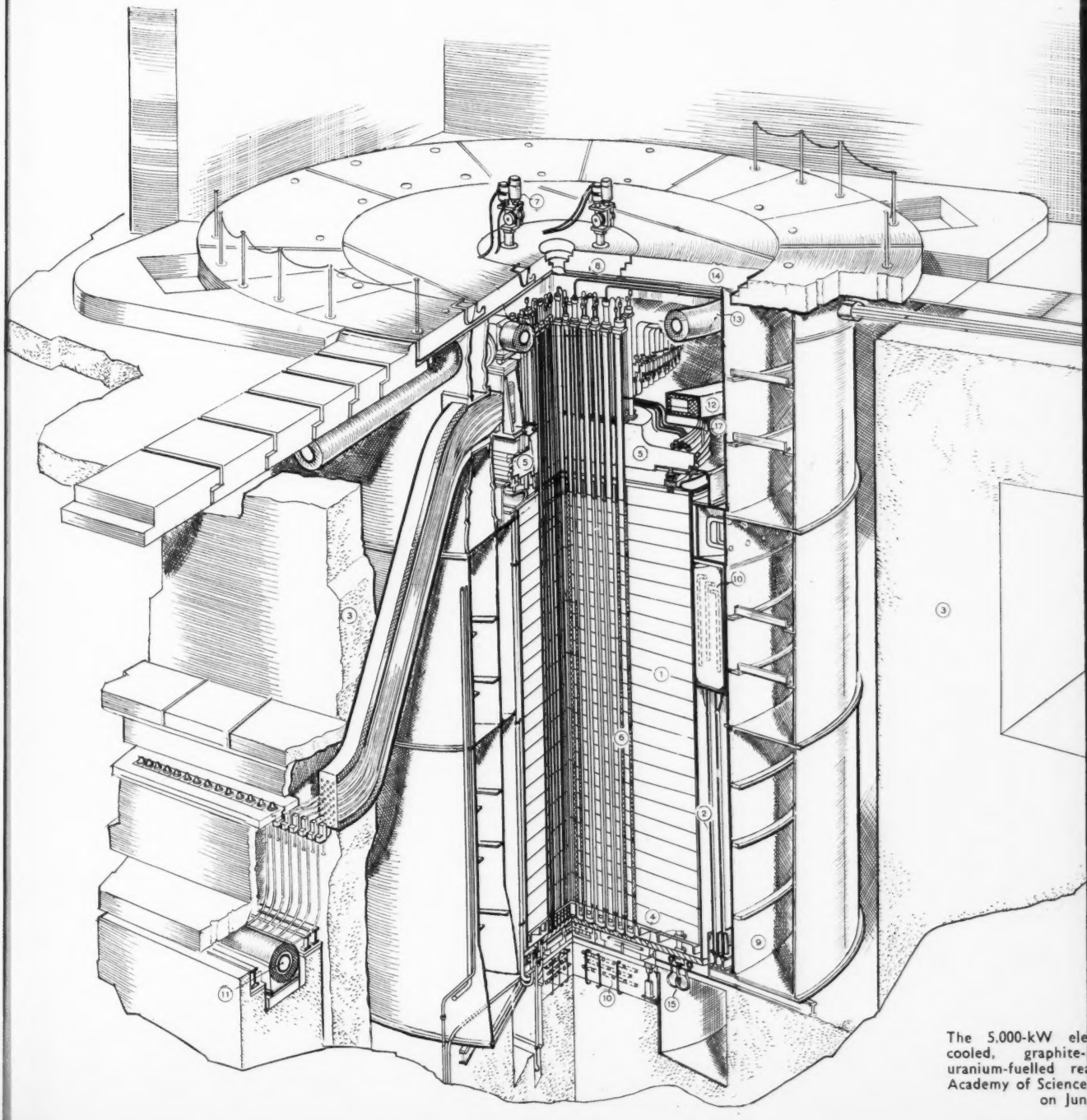
The report concludes with an expression of regret at the death of Dr. A. J. Cipriani, director of the Biology Division.

The World's Reactors

No. 7—5-MW POWER REACTOR

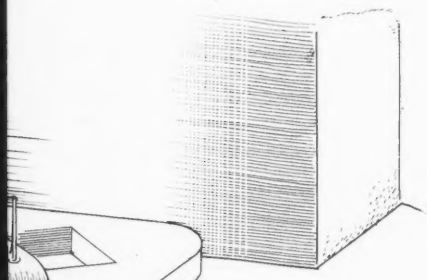
Реактор первой атомной электростанции мощностью 5000кВт, действующей в СССР с 27 июня 1954 года.

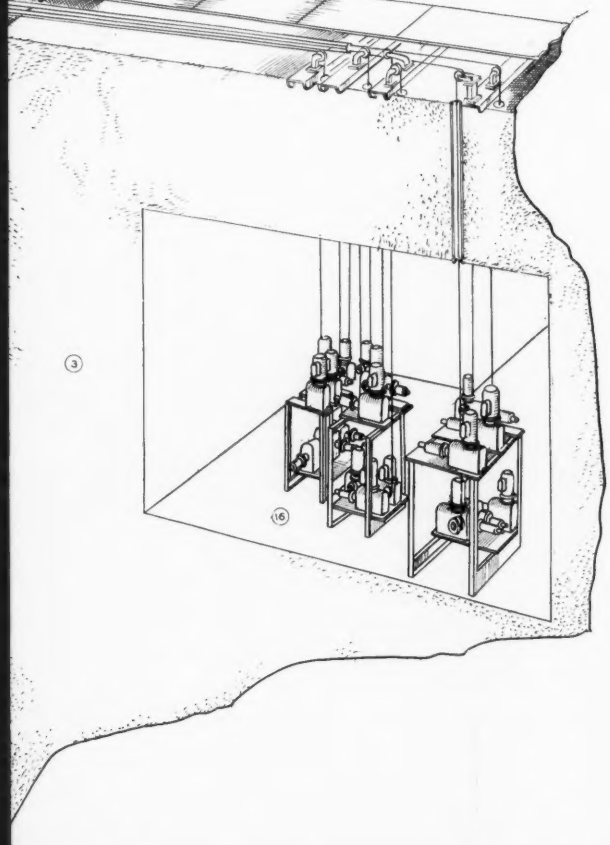
Drawings supplied by the Ministry of Stations of the U.S.S.R., Technical Admi request of the Minister, Mr. G. M.



The 5,000-kW ele cooled, graphite- uranium-fuelled rea Academy of Science on Jun

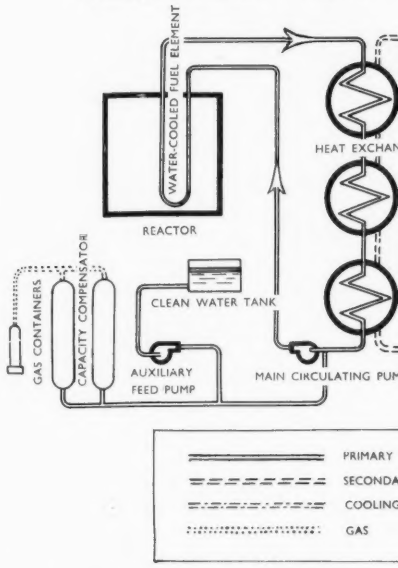
ed by the Ministry of Electrical Power U.S.S.R., Technical Administration, at the the Minister, Mr. G. M. Malenkov.





The 5,000-kW electrical output, water-cooled, graphite-moderated, enriched-uranium-fuelled reactor of the U.S.S.R. Academy of Science. It went into operation on June 27, 1954.

Принципиальная схема



Flow diagram. The primary cooling water ent
(100 atm.) and leaves at 190°C. Steam te

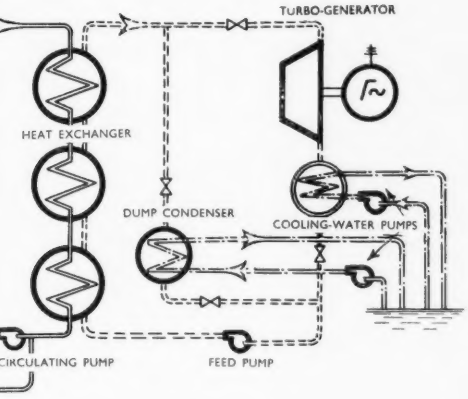
KEY

1. Graphite reflector
2. Containment tank
3. Concrete
4. Bottom Plate
5. Top plate
6. Fuel element
7. Safety-rod servo motor
8. Control rods
9. Water jacket
10. Condenser
11. Water inlet duct to fu
12. Water inlet
13. Water outlet duct fro
14. Cast-iron top shielding
15. Cooled reflector moun
16. Control-rod operating
17. Control-rod coolant pi

Fuel Element (6)

18. Graphite cylinder
19. Water inlet
20. Water outlet
21. Thin-walled stainless s
22. Annular fuel element

Схема электростанции.



PRIMARY WATER CIRCUIT
SECONDARY WATER CIRCUIT
COOLING WATER
GAS

g water enters the heat exchanger at 260-270°C
Steam temperature is 255-260°C (12.5 atm.).

KEY

eflector
nt tank
ate
nt
servo motor
ds
et
t duct to fuel channels
t
let duct from fuel channels
op shielding
lector mounting
d operating mechanism
d coolant pipes
(6)
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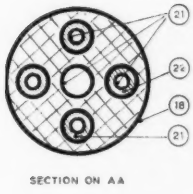
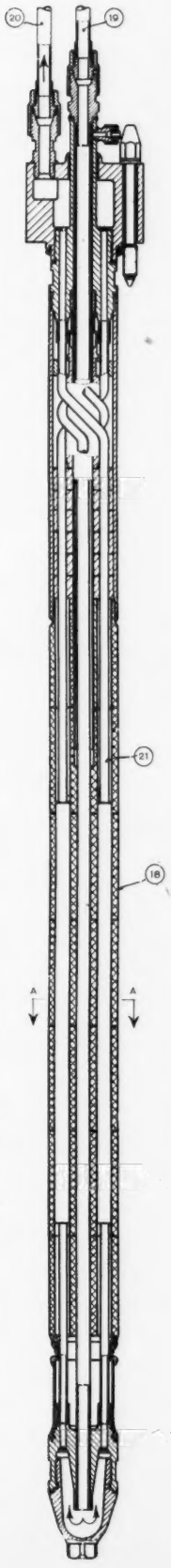


SECTION ON AA

Details of one of the water - cooled fuel-element units.



The World's Reactors—No. 7

5-MW ATOMIC POWER REACTOR

TYPE:	Thermal heterogeneous.
PURPOSE:	Experimental power production.
LOCATION:	Academy of Sciences, near Moscow.
CAPACITY:	5 MW electricity from one turbo-generator. Heat rating: 30 MW. Four pairs of heat exchangers provided—one as stand-by. Maximum flux: 5.10^{13} n/cm.^{2}-sec.
OPERATION:	Commissioned June 27, 1954.
FUEL:	Enriched uranium, 5% U^{235}. U as cylindrical tubes. Stainless steel cladded inside and out. Graphite elements contain four rods, each with cooling channels. Total number of rods: 128. Total charge: 550 kg. Charge for criticality: 260 kg. Maximum graphite temperature: 700°C.
BURN-UP:	0.8 U^{235}—16% of fuel.
CONVERSION FACTOR:	U-Pu: 0.32.
MODERATOR:	Graphite and light water.
CORE:	Overall size: 5 ft. dia. × 5 ft. 6 in. high.
REFLECTOR:	Graphite, in steel tank, N_2 or He pressurized. Overall size: 9 ft. dia. × 10 ft. high (approx.), 5 ft. above, 2 ft. below (approx.).
COOLANT:	Light water at 100 atm. Flows down centre of elements and up fuel tubes. Throughput at peak power: 300 tons/hr. Inlet temperature: 190°C. Outlet temperature: 270°C. Maximum activity: 0.2 c/l. After 1 minute: 2.10^{-5} c/l.
HEAT EXCHANGERS:	Maximum throughput: 40 tons/hr. Pressure: 180 p.s.i. Temperature: 260°C.
CONTROL:	Boron carbide rods, water cooled. Six near-core centre, 12 at extremities. Four additional servo-controlled shim rods, located in reflector. Two safety rods in core.
SHIELDING:	Water: 40 in. radial thickness. Concrete: 120 in. radial thickness.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. BEPO (April, 1956).
No. 2. CP5 (May, 1956).
No. 3. NRX (June, 1956).
No. 4. DIMPLE (August, 1956).
No. 5. ZEUS (September, 1956).
No. 6. CALDER HALL (October, 1956).

Mechanical Induced-Draught Cooling Towers

by

DEREK J. TOW, B.Sc., A.M.I.Mech.E., A.M.I.Chem.E.

Head Wrightson Processes Ltd.

Different water temperatures, made possible by the greater flexibility of the system, necessitate modifications to the power station design conditions. Influence of condenser rating, station load factor and wet-bulb temperature are discussed.

GENERATION of electricity in this country from nuclear energy will be caried out for many years by means of steam-driven turbo-alternators, which, for high thermal efficiency, require the turbines to exhaust to condensers under vacuum. If the generating station is located near a large source of natural water, this water may be directly used for condenser cooling, and the heated water passed to waste. Where by-laws preclude the return of heated water to a river or canal, the water may be partially cooled in cooling towers before being discharged from the plant. Alternatively, evaporative water-cooling towers may be used in a closed circuit. In this system the water is continuously circulated through the cooling towers and condensers, the heat removed from the condensers being passed to the atmosphere partly by the evaporation of some of the water and partly by direct heat exchange with the air. In such a system, make-up water has to be provided to make good the water lost by evaporation in the cooling towers, but the quantity of this make-up water is a small proportion—usually 2%—of the water which would be required for "once-through" cooling.

In the past, most large power stations not located near sources of natural water have been cooled by concrete chimney-type natural-draught cooling towers, but recently investigations have been made by Head Wrightson Processes Ltd., for the C.E.A. into the use of mechanical induced-draught cooling towers (Fig. 1). These studies considered modifications to the design conditions for the whole station, resulting from the different water temperatures which are made possible due to the greater flexibility of the mechanical induced-draught types. This flexibility extends to the ratio of capital cost to running costs of the cooling water equipment and, whereas for a conventional station relatively high investment and low running costs may be preferable, the reverse is likely to be true for nuclear stations.

The aim of the designer of cooling equipment should be to obtain the lowest cost of condensation and not the lowest capital cost for the cooling tower. It is therefore necessary, in making a fair comparison of the suitability of mechanical and natural draught towers, to have an assessment of these costs.

The cost of condensation consists, on the one hand, of the depreciation, interest and maintenance cost of the condenser, cooling-water pipework, water-circulating pumps and cooling tower complete with pond, foundations and operating gear, and, on the other, the power cost for water circulation and cooling tower fan drive. This is calculated as follows:

(a) During winter months, when peak load demand exists, power cost is taken as the sum of the amortized capital charges on additional installed generating capacity required, plus the generating cost of the respective power during this time from the new power station.

(b) For the remainder of the year, when absolute peak load is never required the calculation is first carried out as in winter, and the additional power requirements of fan and pumps beyond winter requirements are calculated without capital charges, but at the generating cost of the most outdated and most expensive power station in operation in the network to which this new power station will supply power.

It has been shown that the mechanical towers generally require lower water pumping costs due to the reduced height of packing when corresponding types of fill are employed in both the mechanical-draught and the natural-draught units, but against this has to be set the cost of operating the fans.

In designing natural-draught cooling towers, since the towers must provide adequate cooling at the time of the year least favourable to such cooling, it is necessary to build very large chimneys. This results in high capital cost. During the winter months adequate cooling could be obtained with very much lower chimneys, as the draught necessary to obtain the required cold-water temperature is less than that required in the summer-time. However, having once been installed, this chimney has to be paid for as if it were being fully utilized all the year round. In the case of mechanical cooling towers, the chimney effect is replaced by propeller-type fans which are low in capital cost.

Irrespective of the construction of the retaining walls, which can be built of either steel, concrete, timber or plastics, mechanical towers are lighter than the corresponding natural-draught tower required for the same duty and for this reason less elaborate foundation work is necessary; in addition, the weight is more evenly distributed across the ground area. In certain situations this can be an important factor, although, in general, nuclear power stations will require reasonable site conditions because of the reactor weight.

The natural-draught towers are built as a small number of large-diameter circular cells, whilst mechanical-draught towers can be built in groups of small cells or units. For

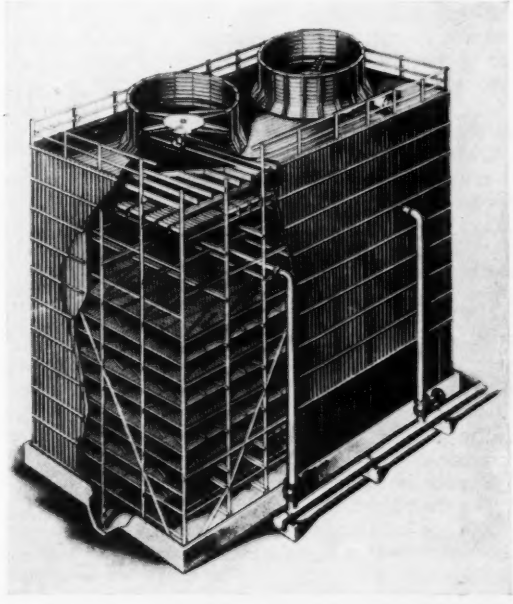


Fig. 1. Typical mechanical induced-draught cooling tower.

this reason, they can be more easily fitted into a crowded site or accommodated to difficult terrain. An additional advantage resulting from this cellular method of construction is that the towers can easily be extended or shut-down in units for maintenance or inspection. This makes the problem of spare cooling capacity much easier, and, in addition, permits greater flexibility of operation, since individual mechanical-draught cells or blocks of cells can be brought in and out of commission to meet fluctuating atmospheric conditions or variable station loading, thus resulting in a substantial reduction in fan power costs.

Amenities. Apart from factors concerning technology and finance, the question of amenities can also favour mechanical-draught cooling towers. Such coolers are of low height, and for this reason cause less public concern over their location near scheduled beauty spots (Fig. 2); they can, of course, be screened by rows of trees, etc. In addition, as they are free of the rigid discipline imposed by the necessary chimney structure of a natural-draught tower, mechanical-draught coolers are more subject to sympathetic architectural treatment.

Another advantage which arises from the low height and inconspicuous nature of mechanical cooling towers is the ease of camouflage in time of war, and the fact that the towers are not of such a height to cause obstruction to aircraft.

In order to avoid any possible nuisance due to the carry-over of water droplets with the air leaving the stack of the towers, drift eliminators can be installed which remove almost all this water from the exit air. In general, the efficiency of elimination increases with the pressure drop which occurs across the eliminators, and because mechanical towers are less sensitive to pressure drop than are natural-draught towers, it is possible to install higher efficiency units than would be economic with the chimney towers.

Fogging. By the very nature of the cooling process, a large amount of water has to be evaporated into the atmosphere and discharged with the exit air leaving the cooling towers. This air is generally hot and saturated, and under certain meteorological conditions a considerable steam plume may be formed. It has been suggested that, whilst this steam plume may be innocuous when discharged from the top of a natural-draught tower at the height of, say, 250 ft. to 350 ft., at the low height of a mechanical-draught tower it might constitute a serious nuisance and blanket the surrounding area at certain times of the year with fog.

It should be remembered, however, that the hot saturated air leaves the mechanical-draught towers from a large number of separate chimneys and hence greater opportunity exists for dilution with fresh air. In addition, the exit air leaves the mechanical-draught towers with a higher velocity than from natural-draught towers and consequently more rapid mixing occurs. Both these factors make mechanical towers less prone to fog formation.

Noise. Whereas, with improper design, fans can create a noise nuisance, present experience indicates that even in closely built-up areas no difficulties arise.

Selection of Cooling Towers for Power Plant

There are four factors which are of major importance when considering the use of cooling towers in conjunction with steam power plant.

(1) The design vacuum and corresponding condensing temperature.
(2) The condenser rating.
(3) The daily load factor variations throughout the year.
(4) The wet-bulb temperature variation.

It is most necessary that the cooling-tower designers obtain information concerning the way in which these items may vary during operation. Unless these data are supplied, it is impossible to make a satisfactory analysis of fan-power consumption, which can markedly influence the overall cooling-tower design.

To give some idea of the effect of these factors, the following points may be mentioned:

The influence of vacuum. There is usually no increase in efficiency of the steam turbine if the vacuum is increased beyond a certain limit. This is due to the fact that as the vacuum increases the volume of the steam also increases, so that friction and velocity-head losses practically offset any possible gain. It is therefore desirable to provide the tower designers with details of the vacuum desired at the various loading conditions at which it is anticipated the steam power plant may operate.

Condenser rating. If the load on the steam turbine varies, the cooling-water temperature should also change. Thus, assuming the circulating water quantity through the condenser remains the same, and supposing the load is reduced

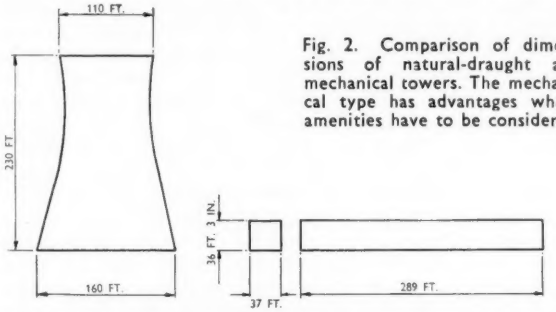


Fig. 2. Comparison of dimensions of natural-draught and mechanical towers. The mechanical type has advantages where amenities have to be considered.

to half the design load, then the temperature rise of the water in the condenser should be reduced by half. If the condensing temperature of the steam is required to be the same as at full load, then the hot-water temperature should remain approximately the same, and the cold-water temperature rise. This is due to the fact that to maintain the same steam-condensing temperature the logarithmic mean temperature difference between the steam-condensing temperature and the cooling-water temperature can be reduced approximately proportionately to the reduction in station load.

Station load factor. The station load factor has a very marked effect on the economy of operation of the cooling tower. For instance, 50% station loading implies approximately 50% heat load to the cooling tower and it follows that the fans could be reduced to half speed at the design conditions of wet-bulb temperature with a power reduction to one-eighth of full load power. As there will also be an appreciable increase in the approach (the difference between the cold-water and the wet-bulb temperatures), as explained above, the actual power saving will, in fact, be much larger than the aforementioned figure. It is therefore most important that accurate information on the anticipated station loading programme should be provided to the tower designers, so that the appropriate estimate of power consumption throughout the year can be made and the most economic cooling tower may be selected. In this connection, it should be noted that economic calculations based on so-called seasonal block-load allocation diagrams do not lead to an adequate demonstration of the economy that can be achieved with two-speed fans. This is because these diagrams are approximated in such a way that a far greater part of the loading is indicated at full load than actually occurs in practice. The variation in actual load is neglected and this has a considerable influence on the actual power requirements of the cooling tower. For instance, if the load of a turbine is reduced to about 80% of full design load at design wet-bulb temperature, then all fans can normally be operated at about two-thirds speed, which means that they require only 30% of the full fan power. A block-load assessment would calculate the full load requirements for 80% of the time and would therefore result in about 270% of the actual kWh consump-

tion. Equally, variations in wet-bulb temperatures have a most marked influence on the actual cost of condensation.

Wet-bulb temperature. It is important to know how the wet-bulb temperature changes throughout the year, so that a sufficiently accurate calculation of the cooling tower operating conditions can be made. If the design wet-bulb temperature chosen is too high, it will mean that the cooling tower design will be too large for the duty and that for most of the time low-speed operation of the fans will be possible. It is interesting to note that in this country, due primarily to the fact that high loading virtually never occurs at times of peak wet-bulb temperature, the Central Electricity Authority invariably specifies a wet-bulb temperature far below the maximum. A similar practice is current on the Continent. For example, in an area where the maximum wet-bulb temperature is possibly 67°F, the design wet-bulb temperature selected is about 45°F and in an area where the maximum is 74°F a design wet-bulb temperature of 53°F is selected. It is, of course, possible that at a high load base-power station a wet-bulb temperature not quite so far from the maximum would be the most economical.

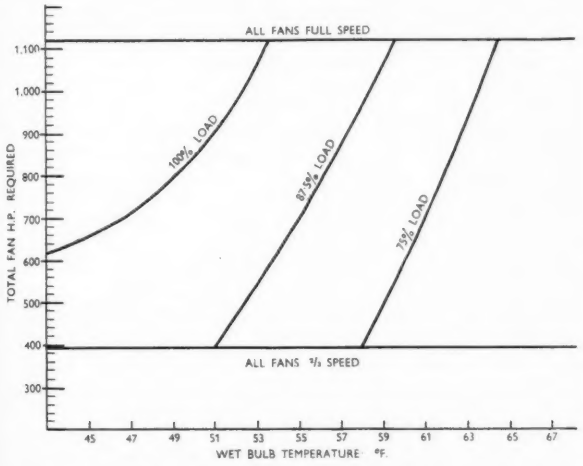


Fig. 3. Effects of reducing rating and wet-bulb temperature on a typical duty for a 110-MW turbo-alternator.

Influence of the Various Factors

Fig. 3 indicates the influence of some of the above items, in particular the effect of:

(a) reduced rating; and

(b) reducing the wet-bulb temperature, on a typical duty for a 110-MW turbo-alternator. It should be noted that in this case the fan operates at either full or two-thirds speed. It has been found that this latter is a very useful operating speed which gives a fan power reduction to less than one-third of the full-speed operating condition and at the same time still permits a reasonably high loading of the cooling tower.

It is realized that it would be difficult to achieve a maximum economy of operation by the direct manual control of the fans in a mechanical-draught cooling tower installation, if the installation contains many fans or if frequent heavy load variations occur. To overcome this difficulty, an automatic method of control has been developed.

Summary

Although, initially, nuclear power stations will be used as base-load stations, and there is probably less advantage in using mechanical as opposed to natural-draught cooling towers than in stations operating with a smaller load factor, attention is being focused on the general economic considerations governing condensation costs.

Tours de Réfrigération à tirage induit mécaniquement par aspiration

Bien qu'en général les avantages économiques de l'emploi de tours de réfrigération à tirage induit mécaniquement par aspiration par comparaison aux tours de réfrigération à tirage naturel soient plus grands dans les génératrices qui opèrent sur des facteurs de charge partiels, l'attention est attirée sur leur emploi même dans les génératrices initiales fonctionnant à partir de réacteurs nucléaires là où des grands placements de capitaux impliquent une fonction de charge de base. Head Wrightson Processes Ltd. ont entrepris des recherches pour la Central Electricity Authority.

Le but général est la production d'une condensation au prix le plus bas possible, mais les considérations de placement de capitaux détermineront dans certains cas des frais d'opération réduits contrebalancés par des coûts élevés en capitaux initiaux, et dans d'autres cas par les conditions opposées. Le système à tirage mécaniquement induit permet une flexibilité de conception considérable. La caractéristique la plus importante est que la puissance des ventilateurs peut être réglée selon les conditions atmosphériques régnantes, alors que dans une tour à tirage naturel les spécifications sont déterminées par le degré de charge atteignant presque le maximum, et les conditions atmosphériques presquent à leur minimum.

Pour obtenir le meilleur dessin possible de telles tours on devra noter avec plus grand soin les relevés des condensateurs, le facteur de charge de station et la température de boule mouillée, plus que ce n'est le cas actuellement.

Kühltürme mit mechanischem Saugzug

Im allgemeinen kommen die wirtschaftlichen Vorteile von Kühltürmen mit mechanischem Saugzug gegenüber solchen mit natürlichem Zug mehr bei unter Teillast arbeitenden Kraftwerken zur Geltung, Neuerdings wird aber auf ihre Anwendbarkeit für die ersten Reaktorkraftwerke hingewiesen, bei denen der hohe Kapitalaufwand den Betrieb als Grundkraftstation bedingt. Die Firma Head Wrightson Processes Ltd. hat für die englische Elektrizitätsbehörde Untersuchungen über die möglichen Vorteile und die Baubedingungen angestellt, die sich für die ganze Station bei den verschiedenen Wassertemperaturen ergeben.

Das allgemeine Ziel ist natürlich Durchführung der Kondensation bei niedrigsten Kosten, doch können in manchen Fällen die Vorteile besonders niedriger Betriebskosten durch hohe Kapitalinvestition aufgehoben werden, und in anderen Fällen verhält es sich umgekehrt. Die Verwendung von künstlichem Zug läss einen ziemlich grossen Spielraum im Aufbau zu. Das hervorstechende Merkmal ist, dass der Kraftbedarf des Gebläses den herrschenden Witterungsbedingungen angepasst werden kann, während bei einem Kühlturm mit natürlichem Zug die Auslegung für fast volle Belastung und ungünstigste klimatische Verhältnisse erfolgen muss.

Um die optimale Leistung aus einem solchen Kühlturm herauszuholen, müsste den Kondensatorablesungen, dem Belastungsfaktor des Kraftwerkes und dem Nasswärmegrad mehr Aufmerksamkeit als bisher geschenkt werden.

Torres de Enfriamiento con tiro Mecánicamente Inducido

Aunque en general las ventajas económicas de usar torres de enfriamiento con tiro mecánicamente inducido en comparación con das torres de enfriamiento con tiro natural son mayores en centrales que funcionan sobre factores carciales de carga, se está llamando la atención al empleo de ellas aun en las centrales de energia iniciales funcionando a base de reactores nucleares donde la elevada inversión capital implica función de carga de base. La firma Head Wrightson Processes Ltd. ha emprendido investigaciones por cuenta de la Autoridad Británica Central de Electricidad.

El objeto general es el de producir condensación al costo más bajo posible pero las consideraciones de inversión de capital decretarán en algunas circunstancias un bajo costo de funcionamiento contrabalanceado por el elevado costo capital inicial, y en otras circunstancias, condiciones opuestas. El sistema de tiro mecánicamente inducido permite considerable flexibilidad en el diseño. La caracteristica más importante es que la potencia de ventiladores puede ser ajustada a las condiciones atmosféricas prevalecientes, mientras que con una torre de tiro natural, la especificación es fijada por carga máxima casi y por poco más o menos las condiciones climáticas máximas.

Para obtener un diseñado óptimo de torres de esta clase, se debe prestar mayor atención a la lectura de condensadores factor de carga de la central y a la temperatura de ampolleta húmeda que lo que es usual en la actualidad.

Problems of Liquid-Metal-Fuelled Reactors

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PART 1

For many years it has been recognized that liquid fuels offer many advantages, but the unfamiliar techniques involved have prevented their early utilization. Part 1 of this article discusses some of their potentialities and follows the arguments that have led to the concentration of research on a limited number of solutions and slurries.

THE present interest in the development of reactors for civilian power requirements is towards highly rated breeder systems with the achievement of short doubling times and high fuel burn-up. Three types of system show promise of attaining this performance; developments of the gas-cooled reactor, which have a high thermal efficiency; pressurized-water reactors of the Shippingport type, in which thermal efficiency is sacrificed for cheap and reliable fuel and constructional materials; and the fluid-fuel reactors which seek to overcome the limitations of solid-fuel elements by the use of unfamiliar technologies.

The fluid-fuel systems comprise the homogeneous aqueous reactor, an example of which has been built and operated at the Oak Ridge National Laboratory, the fused salt reactors, the suspension of UO_2 in a gas stream which is being studied in Holland[1] and the liquid-metal-fuelled reactors.[2] The second Annual Report of the U.K.A.E.A.[3] revealed that work was proceeding in this country on the homogeneous aqueous (H.A.R.) and the liquid-metal-fuelled (L.M.F.R.) reactor systems. In addition, the U.S.A.E.C. has announced that work on a second H.A.R. experiment is well under way and that it has placed a contract for the construction of an L.M.F.R. experiment.[4] It is, therefore, an appropriate time to review the state of technological development of these two types of fluid system and to outline the major problems which have yet to be solved. In this article the L.M.F.R. system will be considered in some detail.

Comparison with other Reactor Systems

The limitations of solid-fuel elements arise from two main causes: first, from growth due to thermal cycling effects; and, secondly, from swelling and loss of reactivity due to fission product build-up. Uranium alloy and ceramic fuel elements give promise of higher burn-ups, but only by completely fluidizing the fuel can these two effects be reduced to a minimum, since growth is then impossible and fission products can be accommodated without distortion and may be removed sufficiently rapidly to maintain a high level of reactivity. In addition to these advantages, the fluid nature of the fuel considerably eases the problems of reactor charge and discharge.

Fissile material in fluid fuels may be present in true solution or in suspension in water, in molten salts or hydroxides, or in liquid metals. Suspension in a gas is not strictly comparable with the other dispersions, for, although it simplifies the handling and distortion problems, it is probably less tractable as far as continuous processing and breeding are concerned. Only the dispersions in water and fused hydroxides constitute homogeneous systems because in other thermal reactors a separate moderator (graphite or beryllium) has to be employed; the term is not relevant to fast reactors. It is, nevertheless, a common mistake to refer to the L.M.F.R. as a homogeneous system.

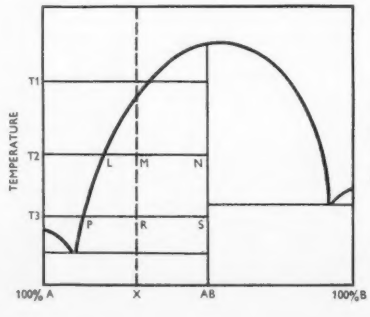

Fig. 1. Equilibrium diagram for a reactive slurry in which temperature changes lead to a change in the solid: liquid ratio.

TABLE I—FUEL MEDIA

Property	Pb	Sn	Bi	Na	Li	Hg	Ga
Melting Point: °C	327	231	271	97.8	179	−38.9	29.9
Boiling Point: °C	1,737	2,270	1,477	883	1,317	357	1,983
Soln. U (at.%) at 500°C	0.02	0.005	0.9	very low	0.01	25	0.1
Thermal cross-section: barns	0.17	0.6	0.032	0.49	67	360	2.8
Corrosion behaviour	←	Fair	→	Good	Fairly Good	Fair	Bad

Only Na can be contained in presence of nickel.

In comparison with the H.A.R. systems, liquid-metal systems have the following advantages:

(i) Higher temperature of operation; H.A.R. systems are limited to the temperature of the critical point of water (370°C), while few liquid metals boil below 800°C and many have much higher boiling points, as will be seen by reference to the list of properties of liquid metals in Table 1.

(ii) Lower pressures; L.M.F.R. pressures are limited to the hydrostatic head of the liquid metal, which, for heavy metals, can be as high as 200-300 p.s.i., but which is small in comparison with the 2,000-3,000 p.s.i. of the H.A.R. systems.

(iii) There is greater flexibility in the choice of systems: both thermal and fast systems appear to be feasible, with internal or external cooling and working as breeders or converters. The thermal systems may be started on U 233, U 235 or plutonium and the fast systems on plutonium-based fuels. The next section shows that there is such a variety of possibilities that it appears at first sight difficult to select the most promising system.

Types of Liquid-metal Fuel

It is important to grasp the fact that a fissile or fertile dispersion in a liquid metal may take one of three forms:

A true solution; this is an atomic-scale dispersion analogous with the solution of uranyl sulphate in water. The solution is in equilibrium with either a pure metal or with an intermetallic compound. In either case, addition of solute beyond the solubility limit produces a precipitate of solid and this, in fact, constitutes the second type of dispersion.

A "reactive" slurry. Fig. 1 shows an equilibrium diagram for the alloy system A-B. At temperature T_1 X% of B is in

true solution in A. On lowering the temperature to T_2, the intermetallic compound AB begins to precipitate from solution until the proportion of solid : liquids is in the ratio LM/MN. At a lower temperature T_3, the ratio has changed to PR/RS. The compound AB has a crystal structure, melting point and properties which are usually quite different from those of A or B. The reason for calling this slurry "reactive" is that a change of temperature produces a change in solid : liquid ratio which can, as will be explained later, lead to undesirable effects such as particle growth and mass transfer.[5, 6]

The reason for growth is that the large particles tend to increase in size at the expense of the smaller ones, since this reduces the total solid surface area and hence the free energy of the system. It is the solubility in the liquid metal of the solid particle material which makes the transfer of atoms from one particle to another possible and which explains the temperature dependence of the growth, for the process is diffusion-rate controlled. It also explains the interest in the third type of dispersion.

A "non-reactive" slurry; in this case the solid and liquid are inert to one another. The solid may be an element (e.g., uranium in sodium) or a compound (e.g., thoria in bismuth). Since the components do not react with one another, it is often difficult to induce the liquid metal to wet the solid and this is an essential condition, for the particles in a non-wetted slurry will prefer the agglomerated state to the dispersed. Apart from non-uniformity of dispersion, the removal of fission products, particularly the volatiles, is rendered more difficult and greater difficulty is likely to be encountered in continuous chemical processing. However, if a stable dispersion can be produced, it should remain so because the tendencies for particle growth and mass transfer are absent.

Fuel Containment

When these slurries or solutions contain fissile uranium or plutonium they may be used in one of the following ways:

(a) Completely sealed in a can which has a void at the top for the accumulation of fission product gases. This is an improvement on the solid-fuel element, since growth will not occur and swelling effects will be diminished. A canned solution or slurry fuel could in many cases replace solid-fuel charges in conventional reactors with beneficial results.

(b) Contained in a can to which charge and discharge pipes were fitted. This system, in which flow could be controlled by gas pressures, could evolve into a plumber's nightmare, since the fuel elements would be highly rated and hence of small cross-section and large in number.

(c) Held in a vessel or calandria through which coolant pipes pass. In this internally cooled system, the fuel investment is low but thermal gradients across coolant pipes may be high.

(d) Pumped round a circuit incorporating a core section, pumps and heat exchangers. This externally cooled system has a large fissile hold-up outside the core, sometimes as much as ten core-volumes. It is, however, more manageable than the internally cooled system and presents simpler construction problems.

If in the canned-fuel elements [(a) and (b)] the fuel is a slurry, the particles may be settled or suspended; in other words, one may or may not introduce some device for agitating the particles. The particles are, however, intense sources of heat and will tend to be agitated on this account and, moreover, should they agglomerate the enhanced heat output should raise temperatures, causing local dissolution and an evenning-up of the particle distribution.

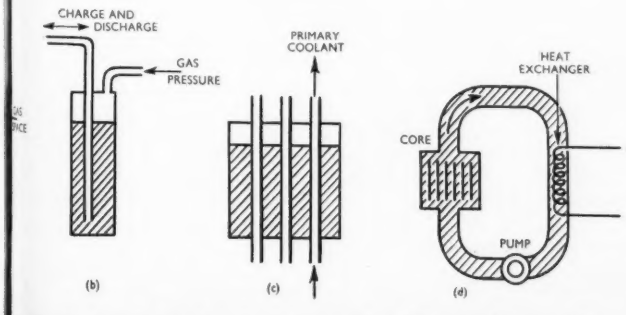

Fig. 2. Various forms that the fuel can take: (a) as replacement for a canned solid fuel; (b) where access to the elements can be accommodated; (c) retained in a cooled tank; and (d) in permanent circulation.

Applications of the Fuels

Having seen what types of liquid-metal fuel can be used, we can now define the requirements for the fuels for thermal and fast systems, and from the known solubility curves and phase diagrams for uranium, thorium and plutonium in various liquid metals select suitable fuels and see what particular problems they present.

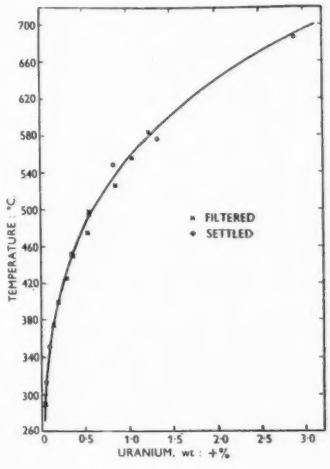

Fig. 3. Solubility curve for uranium in bismuth.

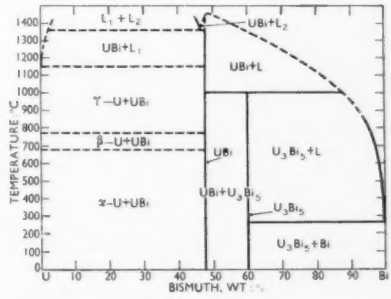

Fig. 4. Equilibrium diagram for U-Bi dispersion at various concentrations and temperatures.

For all types of L.M.F.R. the fuel medium should have the following properties:

(a) A low melting point (less than 400°C) for ease of start-up, and a high boiling point (over 800°C) to prevent evaporation or distillation troubles in the circuit. This restricts the number of possible metals to sodium, lithium, gallium, lead, tin and bismuth.

(b) Compatibility with commercially available constructional materials. This eliminates the highly reactive gallium from the list.

In *thermal systems* the solvent must obviously have a low thermal capture cross-section (that for sodium is about the maximum acceptable) and this rules out tin and natural lithium. In this argument it is assumed that the use of isotopes of low cross-section is not an economic proposition —an assumption which may prove to be unfounded particularly in the case of Li 7 as lithium is the ideal liquid-metal

coolant. One must next decide whether the dispersion in the remaining three elements (sodium, lead and bismuth) is to be a solution or slurry. It happens that only bismuth has a sufficiently high solubility of uranium at modern power station steam temperatures (500-600°C) for use as a true solution fuel. Uranium and sodium do not react with one another and constitute a "non-reactive" slurry fuel. Uranium dissolves in lead to a very limited extent and reacts to give the compound UPb_3 which forms a "reactive" slurry of cubic particles in lead. All three fuels have received serious consideration in the U.S.A. and at Harwell.

The bismuth solution is the most attractive fuel, since there is no difficulty in the maintenance of a uniform distribution of fissile material in a reactor system. Work at Brookhaven[7] has shown that the compatibility problems are not very severe, that commercial steels may be used for structural work and that graphite can be made which is impermeable to bismuth. These compatibility problems will be discussed at greater length in Part 2 of this article. The second in order of preference is the sodium-uranium slurry which is being studied at the Argonne National Laboratory[8] and by the Australian A.E.C.[9] Experience on the N.A.A. sodium-graphite reactor project[10] has shown that sodium is incompatible with uncanned graphite and in this case there is some attraction in using beryllium or beryllia as moderator.

Although the "reactive" UPb_3-lead slurry has the disadvantages of its type it is still worthy of consideration, since irradiation effects and high flow rates may overcome these. However, the other two types of system are sufficiently more attractive for it to be neglected for the present time.

For a *fast system* the fuel solvent is less restricted by cross-section requirements than for thermal reactors. On the other hand, moderating materials should be absent because of criticality considerations and, in general, the heavier elements are preferable to the light. Lithium has some moderating effect and is therefore excluded from the possible metals. Sodium, lead, tin and bismuth are once again the most suitable solvents. No uranium-based solution is sufficiently concentrated even at fairly high temperatures for

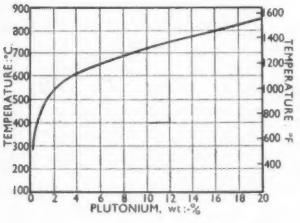

Fig. 5. Solubility curve for plutonium in bismuth.

consideration as a fuel. The actual concentration required for a fast system is not known with certainty, but it is probably of the order of 10% fissile material. It is perhaps a fortunate coincidence that the solubilities of plutonium in liquid metals are greater than those of uranium at similar temperatures, since plutonium, with its high η value for fast fission, is the better fast-reactor fuel. The only system for which an accurate solubility curve is available is plutonium-bismuth in which Pu has a solubility of 10% at just over 700°C. This means that a fast system based on this fuel would operate at a high temperature and severe compatibility problems could arise.

It is unlikely that a slurry would ever be seriously considered for a fast system unless it were canned, as it is very important that the fissile material should be homogeneously dispersed throughout the core. In addition, a fast reactor would preferably be internally cooled to keep the fissile investment to a minimum. One can see therefore that only two types of fast L.M.F.R. system appear to be of interest: a canned slurry reactor (the choice of canning material being wider than for a thermal system) on fairly conventional lines

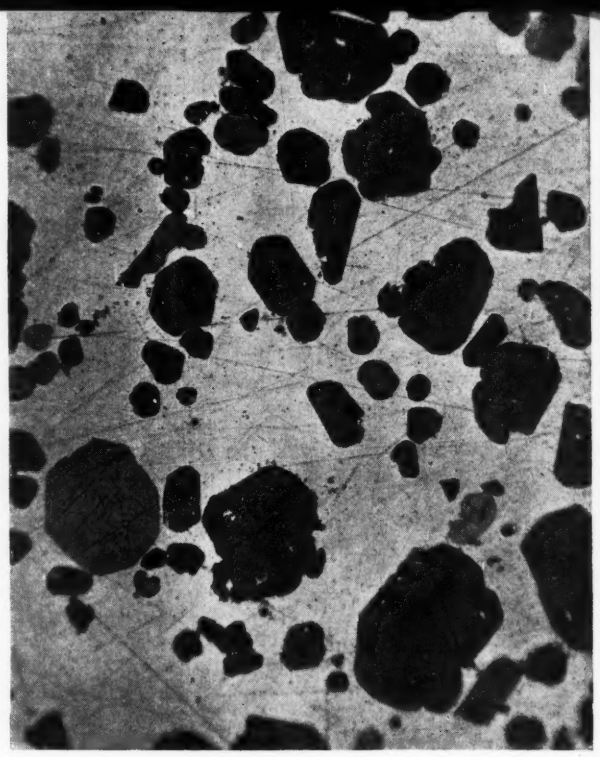

Fig. 6. Slurry particles accumulating in a cold part of an experimental circuit.

or a solution core, internally cooled, operating with a high fluid temperature.

At present, however, no fast L.M.F.R. is under development and of all the systems discussed, both fast and thermal, it is significant that only two have been selected for immediate attention; Brookhaven National Laboratory and the U.K.A.E.A. are seriously examining thermal systems using uranium-bismuth solution fuel, whilst the Argonne National Laboratory and the Australian A.E.C. are looking at the uranium-sodium slurry fuel thermal systems.

Breeder Blankets

Liquid-metal fuels are ideally suited for breeder or converter reactors, since it is possible to obtain good breeder blanket coverage of the core without the difficulties of high-pressure systems. The core vessel need only be a physical barrier to the passage of liquid, since it is virtually floating in a metal bath; for example, a $\frac{1}{4}$-in. thick beryllium vessel is probably adequate for an L.M.F.R. with a core weighing 15 tons. It is possible to define the conditions which an L.M.F.R. blanket must fulfil. They are as follows:

(i) The blanket must surround the core as completely as possible to effectively trap all escaping neutrons.

(ii) The concentration of fertile material should be as high as possible, consistent with—

(iii) the fluidity being sufficiently high for easy handling.

(iv) For reasons of safety, the blanket solvent should be the same as that for the fuel. Introduction of quantities of a "foreign" liquid into the core could prove to be an embarrassment.

(v) Extraction of the fissile material by a cheap process is important to the overall economy of the reactor.

The logical consequences of these conditions are that the blanket must be a slurry in which the solid concentration should be well below 25% by volume and the particle size small to prevent self-screening effects and to facilitate processing. This slurry should, of course, remain in uniform suspension during its time in the blanket annulus. However, with the accumulation of fissile material heat would be developed by fission and at equilibrium the blanket might contribute as much as 25% of the total heat output of the reactor. This heat would be removed via heat exchangers

Fig. 7. Large particles formed in areas of relatively low temperature.

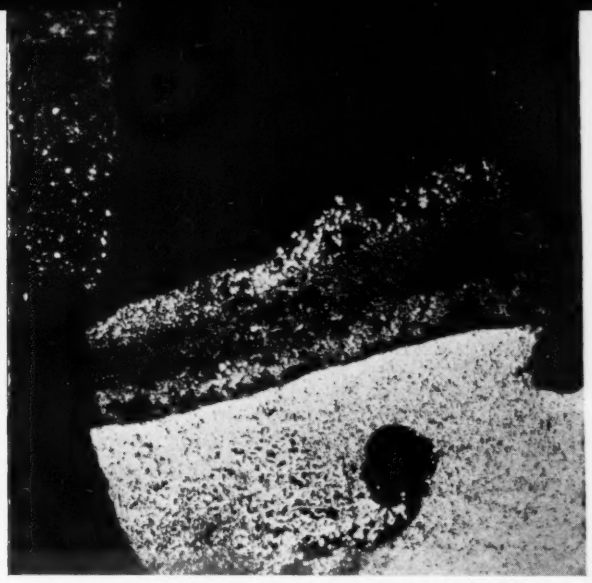

Fig. 8. View from above of a slurry bath with a horizontal temperature gradient maintained across it.

so that a temperature gradient would exist through the blanket, a condition which has been shown to cause trouble in "reactive" slurry circuits.

The experimental data so far obtained[5] have come from thermal convection loop and pot experiments in which it has been found that the slurry particles move down the temperature gradient and deposit at the coldest part of the loop (irrespective of the position in the circuit). The exact mechanism of this is not certain, but it is due in some way to the variation in solubility of the thorium or uranium in the liquid with change of temperature and to the growth of large particles at the expense of the smaller. This behaviour will certainly be modified when the flow rate is increased and the particles are producing heat from fission, as they will be in a reactor. Moreover, if the liquid is a heavy metal it will be heated to a considerable extent by γ-capture. The resulting behaviour of the particles can only be examined by carefully controlled irradiation experiments.

The "reactive" slurries do possess one advantage which tends to outweigh the likely disadvantages and that is the possibility of simple processing.[11] It is most unlikely that thorium, uranium and protoactinium dissolve to the same extent in a solvent metal at a given temperature. It is theoretically possible, therefore, to effect some separation by a fractional crystallization process. In the case of the L.M.F.R. system the blanket consists of a suspension of the compound Th_3Bi_5 in bismuth. The solubility of uranium in bismuth is much higher than that of thorium, and by heating to a high temperature to get both elements into solution and then cooling to a low temperature the uranium tends to concentrate in the liquid and the thorium in the solid. However, the fate of the 27.4-day half-life Pa 233, parent of U 233, is at present uncertain. If it partitions with the thorium, subsequent processing of the liquid is simplified as the high thermal cross-section and epi-thermal resonance of protoactinium make its exclusion from the core circuit desirable. Both U 233 and Pa 233 neutron capture lead to build-up of non-fissile U 234 and it may be necessary to have several hundred parts per million solubility in hand to allow for this.

For fast systems it is doubtful whether a fluid blanket is feasible, since the high flux density round the small core and the low capture cross-section of uranium or thorium would require a very thick slurry blanket and it is probable that a solid such as ThO_2 would be used. This could then be run at any temperature up to that at which sintering begins to take place (i.e., over 1,000°C for ThO_2).

Chemical Processing

The possibility of cheap and simple depoisoning of the fuel is one of the main attractions of liquid-metal systems. In recent years a great deal of work has been done on the development of high-temperature methods of processing solid-fuel elements and much of this work is relevant to the processing of liquid fuels, since its aim is the simple and rapid removal of high cross-section fission products.

In the systems under consideration, processing has two objects; the maintenance of the level of reactivity and the maintenance of the fissile element in solution or suspension. The former object applies particularly to thermal systems, the latter to fast.

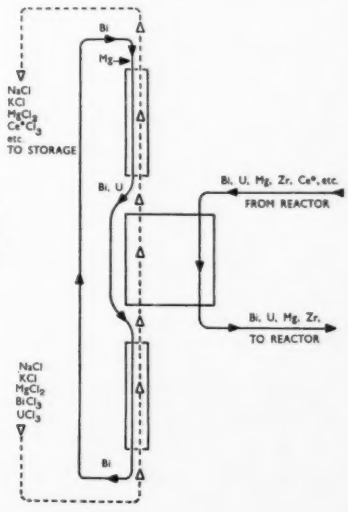

Fig. 9. Flow sheet for fission-product extraction by a fractional crystallization process.

The fission products are usually divided into three groups for processing purposes[12]:

(i) those which volatilize at the core temperature (the rare gases Kr and Xe, the halogens Br and I, and certain metals such as Cd, Zn and Cs);

(ii) those with chlorides more stable than uranium trichloride; and

(iii) those with chlorides less stable than uranium trichloride.

The philosophy of the treatment is to remove group (i)

elements into the reactor blanket gas by sparging or similar degassing treatments while group (ii) is removed by contacting with fused chlorides by reactions of the type:

$$3\ NaCl + Ce \longrightarrow CeCl_3 + 3\ Na.$$

The high cross-section elements are concentrated in these two groups and the processing of group (iii) is less important from the reactivity point of view. However, it does include elements such as molybdenum and niobium which may alloy with the dissolved uranium, and in so doing form a precipitate of an intermetallic compound whose density differs so considerably from that of the fuel solvent that it separates out and depletes the fissile concentration. It is this effect which is likely to be of overriding importance in a fast system, i.e., a pure alloying effect, not a nuclear effect.

In theory, the removal of volatile fission products would appear to be a simple task by conventional engineering techniques such as reduction in pressure above the liquid surface or the use of a fountain degasser. This is true if all the volatiles rise with the liquid, but some may be adsorbed on the walls of the vessel or on the moderator and be difficult to remove. If Xe 135, with a thermal cross-section of 2.6×10^6 barns and a half-life of 9 hours, were trapped the reactivity would fall rapidly. The ideal way of dealing with Xe 135 would be to remove its precursor I 135 which has a half-life of 6.7 hours. However, it is believed that only half this element is removed as vapour, the remainder being removed in the salt contactor or having sufficient time to decay to xenon. It is therefore essential that an efficient degassing scheme forms an integral part of the reactor system.

The elements extracted in the fused-salt stage are the rare earths and the alkali and alkaline-earth metals. Among these are some high cross-section elements such as Sm 149 (50,000 barns), Gd 157 (160,000 barns) and Eu 155 (14,000 barns).

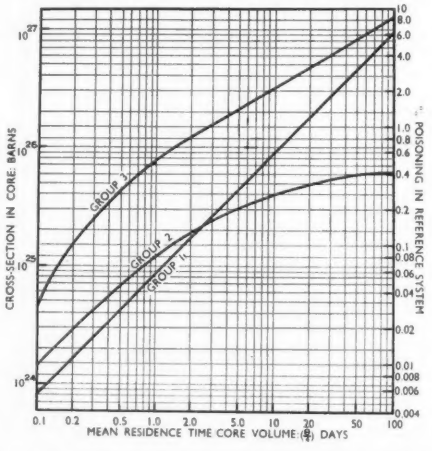

Fig. 10. Build up of fission-product poisoning after start-up Groups 1, 2 and 3 refer to volatiles and elements which form relatively stable and unstable chlorides respectively.

The increase in poisoning with time for this group of elements is shown in Fig. 10, expressed as total cross-section and as percentage poisoning of the total neutron absorption by uranium, bismuth and fission products. For economic operation of the reactor, the poisoning due to fission products should be kept well below 5% or roughly to an allowance of a maximum of 1% for each of the three groups. This means that the volatiles must be processed very rapidly (about 1 core volume every half-hour), the group (ii) elements 1 core volume at least once every three days and group (iii) at much less frequent intervals (say every 100 days).

The salt which oxidizes the group (ii) elements can be one of three: magnesium chloride, uranium chloride or bismuth chloride, mixed with other chlorides, e.g., NaCl and KCl to lower the melting point.

Using $MgCl_2$, the Mg and $MgCl_2$ are always in great excess over the fission product elements and chlorides and the process maintains its rate right up to completion of the oxidation; this is known as a "buffer" process.

UCl_3 has the advantage that it is a neat way of helping to make up the fuel losses, but it has to be supplemented by additions of metal.

With $BiCl_3$, exactly the right amount, and no more, must be added to oxidize the group (ii) elements; excess will convert uranium to chloride. This is known as the "stoichiometric" process.

A high degree of control over these processes can probably be exerted by application of a potential across the salt bath using a molten bismuth (fuel) cathode.

A problem which arises in the processing of highly rated systems is the very high rate of heat generation of the fission products which restricts the extent to which they can be concentrated in processing plants. This also limits the use of evaporation as a stage in processing. The heat can, of course, be very useful in keeping the salts molten and even in contributing to the reactor output. In the case of the bismuth-based L.M.F.R., the production of polonium is another useful source of heat and of intense α-activity which may be used, for example, in catalysing the production of nitric acid from moist air. Polonium will probably be collected in the traps of the volatile fission product-removal plant, as it is fairly volatile at 400-500°C. It is produced at the rate of

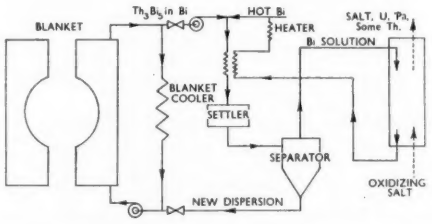

Fig. 11. (Above) Flow sheet for breeder blanket in the Brookhaven National Laboratory system.

Fig. 12. (Below) Simplified overall flow sheet for the B.N.L.'s L.M.F.R. system.

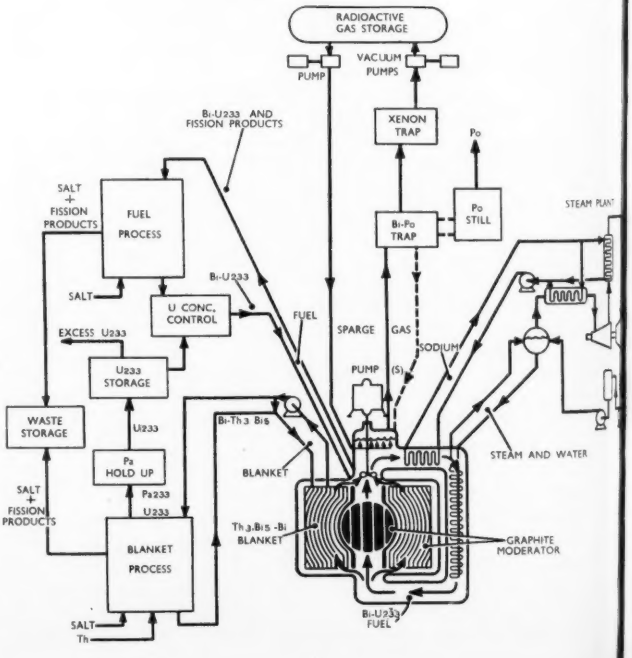

TABLE 2: L.M.F.R. PERFORMANCE (B.N.L. SCHEME)

OUTPUT:	Thermal: 550 MW Electrical: 210 MW
FUEL:	700 p.p.m. U 233 dissolved in bismuth
BLANKET:	10% thorium as Th_3Bi_5 slurry in Bi
TEMPERATURES:	Maximum: 550°C Minimum: 425°C
U 233 FISSILE INVESTMENT:	Core: 9.4 kg Core + core circuit: 165 kg Blanket 23 kg Total: 188 kg
RATING:	1.1 MW (electrical) per kg U 233
BISMUTH INVESTMENT:	Core circuit: 250 tonnes Blanket circuit: 230 tonnes Total: 480 tonnes
ESTIMATED CONVERSION FACTOR:	1.05
PEAK FLUX (THERMAL):	4-5 x 10^{13} n./cm.^{2} —sec.
FLOW CONDITIONS:	10 ft. per sec. in core, or 36,000 g.p.m.
DIMENSIONS:	Core: 5 ft. dia. x 5 ft. high Core vessel: 12 ft. dia. x 15 ft. high Bismuth : graphite ratio 1 : 1

25.2 gm per day in a 500-MW power reactor[13] to reach a final equilibrium value of 9.1 kg of polonium in the blanket and core circuits, which represents a heat output of 1.3 MW and an α-activity of 4.1×10^7 curies.

The group (iii) elements (often referred to as the "noble" fission products, due to their low chemical reactivity) may be dealt with in one of two ways; some of the elements, such as molybdenum and niobium, have very low solubilities in bismuth and will probably separate out to a free surface such as at the degassing plant where a physical removal may be possible. Others, such as ruthenium and zirconium, are quite soluble in bismuth and when their removal is necessary it is probable that a specific process will have to be employed, e.g., a liquid-metal extraction or even a wet process. Since this processing stage is relatively infrequent, the emphasis on cheapness is not so essential.

Plant Layout and Performance

The steam-raising and chemical processing schemes of the L.M.F.R. system lead to a layout similar to those associated with other large chemical plants. The Brookhaven layout in Fig. 12 is purely schematic and takes no account of the engineering details of the plant which are largely fixed by the properties of the materials of construction. Corrosion considerations limit the temperature and flow rates, and hence the thermal efficiency in the generation of electricity. In the second part of this article the determination of the operating conditions of a bismuth-based L.M.F.R. by the material characteristics will be discussed, together with an assessment of the ways in which improvements may be sought.

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Problèmes soulevés par les Réacteurs à combustible métal liquide

La tendance actuelle du développement des réacteurs pour les besoins d'énergie civile se porte vers les systèmes créateurs à puissance nominale élevée avec les accomplissements de températures de doublage courtes et d'une consommation de combustible élevée. Trois genres de systèmes ont semblé promettre l'obtention de ce résultat—le réacteur à température élevée refroidi au gaz, le réacteur aqueux homogène et le réacteur à combustible métal liquide. Ce dernier peut fonctionner à des températures élevées et à des pressions réduites et peut être adapté au fonctionnement thermique ou rapide. Le combustible peut être sous forme d'une vraie solution, de pâte aqueuse réactive (dans laquelle le changement de température produit un changement dans le rapport solide/liquide), ou de pâte aqueuse non réactive. On devra noter que tout à fait hors des systèmes de réacteurs à combustible métal liquide il y a des avantages à l'emploi de combustibles fluidisés de ce genre pour remplacer les combustibles solides en boîte actuellement employés dans les systèmes plus conventionnels. Du nombre de solutions et pâtes aqueuses possibles, celles de l'uranium ou plutonium dans le bismuth offre les plus grandes possibilités tandis que la couverture-créateur consisterait probablement en une pâte aqueuse non réactive de thorium-bismuth en bismuth, par exemple.

Probleme der Flüssig-Metall-Reaktoren

Die Entwicklungstendenz im Bau von Leistungsreaktoren für den zivilen Bedarf geht zu den schnellen Brutreaktoren mit Temperaturverdoppelung und hohem Burn-up-Faktor hin. Drei Typen scheinen für Erreichen dieses Zieles besonders geeignet zu sein, und zwar der gasgekühlte Hochtemperaturreaktor, der homogene Reaktor und der Flüssig-Metall-Reaktor. Dieser kann bei hohen Temperaturen und niedrigen Drücken arbeiten und lässt sich für Wärme bzw. hohe Leistungsdichte einrichten. Der Brenstoff kann in Form einer Lösung, einer reaktiven Suspension, in der die Temperaturveränderungen Veränderungen des Mischungsverhältnisses der Feststoffe und Flüssigkeiten nach sich ziehen, oder einer nicht-reaktiven Suspension benutzt werden. Es ist dabei zu beachten, dass den verflüssigten Brenstoffen, neben ihrer Verwendung in den spezifischen Flüssig-Metall-Reaktoren, eine grosse Bedeutung als Ersatz für die in den konventionellen Reaktorsystemen benutzten festen Canningmaterialien zukommt. Von den in Frage kommenden Lösungen und Suspensionen scheinen diejenigen von Uran oder Plutonium in Wismut die grössten Erfolgsaussichten zu haben, während der Brutstoff wahrscheinlich aus einer nicht-reaktiven Suspension von z.B. Thorium-Wismut in Wismut bestehen würde.

Los Problemas de Reactores Alimentados con Metal Liquido

La tendencia actual en el desenvolvimiento de reactores para las necesidades civiles de energía es hacia sistemas criadores de regimen elevado con las realizaciones de temperaturas dobladoras cortas y elevado quemado de combustible. Hay tres tipos de sistema prometedores de la obtención de este "performance"—el de reactor de alta temperatura enfriado con gas, el de reactor acuoso homogéneo y el de reactor de combustible de metal liquido. El L.M.F.R. (reactor alimentado con metal liquido) está en condiciones de operar a temperaturas elevadas y a bajas presiones y puede ser adoptado para operación térmica o rápida. El combustible puede tener la forma de una verdadera solución, pasta aguada reactiva (en la que el cambio de temperatura produce un cambio en la relación sólido/liquido), o una pasta aguada no reactiva. Deberá notarse que, prescindiendo completamente de los sistemas L.M.F.R. especificos, hay ventajas en el uso de combustible licuado de esta naturaleza para reemplazar los combustibles envasados y sólidos que se emplean actualmente en los sistemas más convencionales. Del número de posibles soluciones y pastas aguadas, las del uranio o el plutonio en bismuto ofrecen las más grandes potencialidades, mientras que la "frazada criadora" probablemente consistiría de una pasta aguada no reactiva de, por ejemplo, torio-bismuto en bismuto.

Swiss Heavy-Water Research Reactor

Second Stage of Industry's Atomic Energy Developments at Würenlingen

THE 12.5-MW heat output, heavy-water research reactor which is to be built by Reactor A.G. at Würenlingen, Switzerland, is due to go into operation early in 1959. Switzerland has not the financial resources of countries such as America and Britain and, of necessity, a research instrument of the widest versatility was called for to supplement the rather limited resources of the swimming-pool reactor bought from the U.S.A. in 1955.

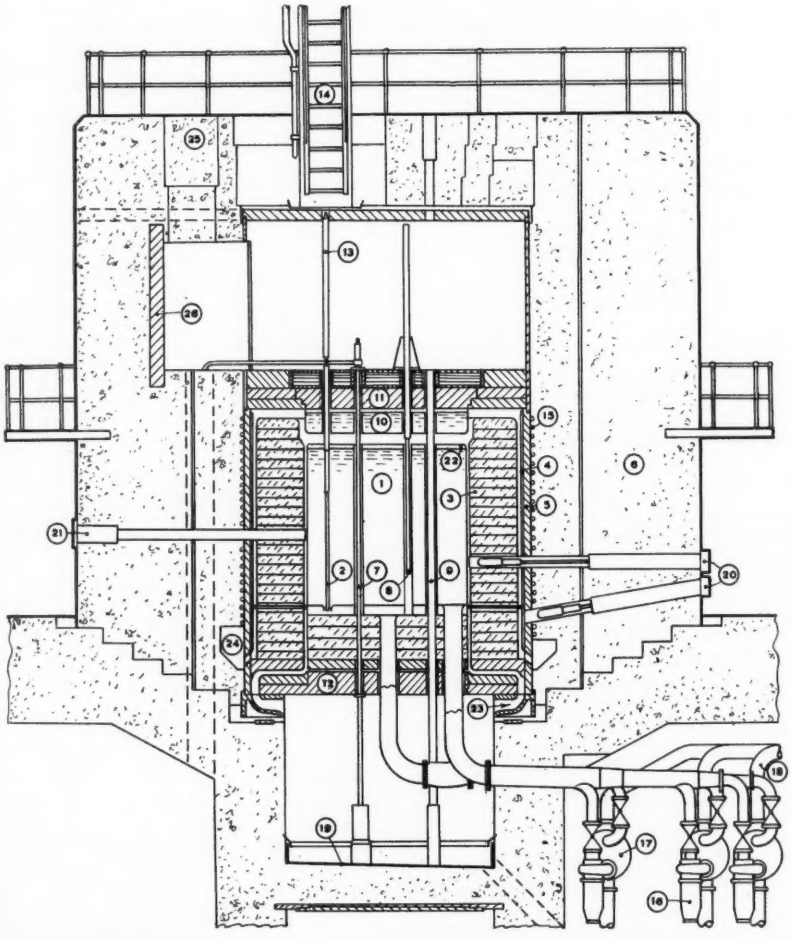
Its main purpose is to provide data for future power-station designs, and the experimental facilities provide for high-temperature research, materials testing and the development of ancillary equipment as well as the production of radio-isotopes and the training of personnel. The facilities comprise seven vertical hot loops of 2.75 in. and 4.75 in. diameter, four vertical isotope production channels, six vertical irradiation channels, and a horizontal through-beam channel in the core and a beam channel to the centre of the core. In the reflector there will be eight vertical isotope production channels, twelve horizontal channels of 6 in. diameter and three large facilities 10 in. and 20 in. square. The hot loops will enable investigations to be carried out at temperatures considerably above the temperature of the reactor. In these channels, which are independent of one another in respect of circuit and temperature, various types of fuel elements and coolants can be examined.

The core comprises an aluminium tank 7.5 ft. in diameter by 7.9 ft. high, through which the heavy-water moderator will be pumped at a rate of 2,580 g.p.m. The maximum temperature of the moderator is designed to be 52°C, the rise between inlet and outlet being 15°C. About 10 tonnes of heavy water is to be used in the circuit. The core will be cooled by air blown at 100-200 c.f.m. This air flows between the tank and the radial graphite reflector and between the graphite and thermal shield.

The uranium fuel rods are 1 in. in diameter, 7.4 ft. long, clad with aluminium 0.060 in. thick. The 244 elements are arranged on a regular square lattice of 4.85 in. pitch.

The control system comprises three safety rods, three groups of two rods for coarse control and two fine control rods. Coarse control is also obtained by varying the height of the heavy water.

Graphite is used as the reflector radially and beneath the core tank; a tank of light water forms the top reflector. The radial thickness of the graphite is 2.33 ft. Outside the graphite there is a boron neutron-absorber backed by a cast-iron thermal shield 6.3 in. thick. Behind this there is a 2.6 ft. thickness of concrete (poured exceptionally wet) and a further 5.2 ft. of barytes concrete. A pumped water-cooling system is interposed between the thermal shield and the concrete. The bottom shielding comprises cast-iron plates, upon which the graphite rests, and concrete. The top shielding is of cast iron, water



1. Heavy-water moderator
2. Natural-uranium fuel element
3. Graphite reflector
4. Boron neutron-absorber
5. Cast-iron thermal shield
6. Concrete
7. Hot-loop channel
8. Cadmium control rods
9. Irradiation channel
10. Light water
11. Top cast-iron shield
12. Bottom cast-iron shield
13. Fuel-handling apparatus
14. Charge-machine track
15. Water cooling
16. D_2O pump
17. Heat exchanger
18. Cooling water
19. Drainage sump
20. Irradiation channels
21. Horizontal beam channel
22. Helium
23. Cooling-air inlet
24. Air-collection annulus
25. Access hole
26. Cast-iron shield

Section through the Reactor A.G. heavy-water research reactor. It is due to go into operation early in 1959.

TYPE:	Thermal heterogeneous.
PURPOSE:	General physical research, reactor technology research (hot loops), isotope production.
LOCATION:	Reactor A.G. Würenlingen, Switzerland.
POWER:	12.5 MW heat.
OPERATION:	Beginning of 1959.
FUEL:	Natural uranium, approx. 6 metric tons.
	Cylindrical bars, 1 in. dia., 7.4 ft. long.
CLADDING:	Aluminium, 0.060 in. thick.
MODERATOR:	Heavy water, approx. 10 metric tons.
	Maximum temperature: 52°C.
CORE:	Aluminium heavy-water tank, 7.5 ft. dia., 7.9 ft. high.
	Lattice: square lattice, 4.85 in. pitch.
	Number of fuel elements: 244.
REFLECTOR:	Bottom and radially: graphite.
	Top: light water.
	Radial thickness of graphite: 2.33 ft.
COOLANT:	Heavy water, forced convection.
	Flow rate: 2,580 gal./min.
	Temperature rise: 15°C.
	Moderator cooling: air, 100-200 ft.³/sec.
FLUX:	Maximum thermal neutron flux: 2.5×10^{13} n/cm²-sec.
CONTROL:	Safety: three rods.
	Coarse control: three groups of two rods each, or height of D_2O.
	Fine control: two rods (one only in operation).

EXPERIMENTAL FACILITIES:

In core:	Vertical:	Seven hot loops, 2.75 in. and 4.75 in. dia.
		Four isotope production channels, 2.75 in. square.
		Six irradiation channels, 2.75 in. and 4.75 in. dia.
	Horizontal:	One through beam channel.
		One beam channel to centre of core.
In reflector:	Vertical:	Eight isotope production channels, 2.75 in. dia.
	Horizontal:	Twelve experimental channels, 6 in. dia.
		Three large facilities, 10 in. and 20 in. square.
SHIELDING:	Top shields:	Cast iron, water cooled.
		Steel and hydrocarbon.
		Heavy carbon.
	Bottom shields:	Cast iron.
		Concrete.
	Radial shields:	Cast iron 6.3 in. thick, water cooled.
		Concrete with high water content, 2.6 ft. thick.
		Heavy concrete, 5.2 ft. thick.
OVERALL SIZE:	Diameter:	29.5 ft.
	Height:	23.1 ft.

cooled, steel charge and discharge working face, and concrete. The overall diameter of the reactor is 29.5 ft. and the height is 23.1 ft.

Directly below the reactor is the charge and discharge apparatus for servicing the vertical hot-loop channels and the irradiation channels. Also below the reactor are located the heavy-water pumps, air blowers, hot-loop control rooms and high-temperature research room.

The reactor is being built on a 60,000 m² site at Würenlingen by Reactor A.G. under the auspices of the Swiss Study Commission for Atomic Energy. The estimated cost of the establishment amounts to about £2 million, made up as follows:

Research reactor ...	£600,000
Laboratories	500,000
Heavy water	550,000
Uranium	130,000
Graphite	35,000
Swimming-pool reactor	180,000

Swiss industry is co-operating wholeheartedly in the project and Reactor A.G. is a direct result of this co-operation. In 1951, three of the major Swiss concerns—Brown Boveri, Escher Wyss and Sulzer Bros.—agreed to co-operate in the field of nuclear research. Various projects were drawn up, leading in 1953 to initial proposals for an experimental industrial reactor. Reactor A.G. was founded on March 1, 1955, with the financial co-operation of over 125 companies. Industrial concerns provided 49% of the capital, the Brown Boveri - Escher Wyss - Sulzer partnership 31%, and banks, research institutions and finance houses 20%.

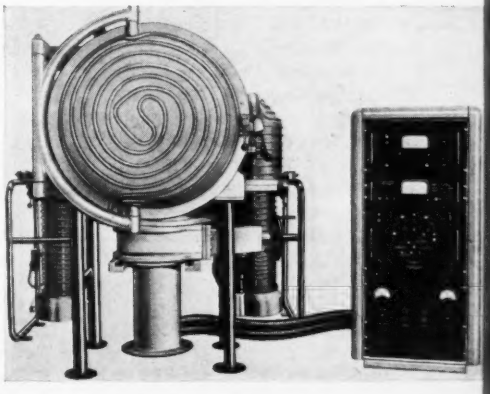
High-Vacuum Furnace

Developments in the field of vacuum metallurgy have stressed the importance, for purification with the charge hot, of operation at pressures below those of dissociation of the oxides and quick access to the mould without incurring the danger of thermal shock to the crucible. The new range of Via-Vac F25H high-vacuum furnaces is said to satisfy these demands. They have been designed to melt and cast or sinter metals at low pressures using resistance or high-frequency induction heating.

The vacuum work chamber is made of mild steel with a polished stainless steel lining and has an internal diameter of 30 in. The crucible is 6 in. internal diameter and 12 in. high. Taking the packing factor as 1.5, a charge of 25 lb. of steel can be accommodated. A number of charging buckets can be accommodated within the work chamber, additions being made at will by an external selector mechanism. Charges may be added through a vacuum lock. If required a needle valve may be incorporated on the work chamber so that inert gases may be introduced and pressure maintained at a prescribed level.

All high-vacuum valves are power operated and controlled from rotary switches on a graphic display panel in the control rack. Pressure measurements may be taken at various points by means of ionization and thermocouple gauge heads.

The makers are Vacuum Industrial Applications Ltd., Wishaw, Scotland.



Via-Vac high-vacuum furnace.

The Rolling of Metals under Laboratory Conditions

Possibilities of the Small Combination Mill

ROLLING small quantities of metals for research and experimental purposes is a very different matter from rolling on a production basis. In production work, the primary consideration is output and the mill is designed to that end, the number of stands and the reduction effected in each being "tailored" to suit the type of material being worked and the relative sizes of the input and output of material, and each stand is, practically speaking, a one-purpose unit.

In experimental and research work, however, high production is quite unimportant, and the primary requirement is flexibility in operation; the ability to cope with a very wide range of operating conditions. It is obvious, even to those unversed in rolling techniques, that a tungsten slug and thin copper shim must present completely different requirements as regards power input, roll pressure and optimum roll diameter. Heavy reduction of thick material calls for rolls of comparatively large diameter; precision rolling of thin material is best dealt with by small rolls and a moment's thought will show why this should be so. Large-diameter rolls give a much "flatter" contact and this deformation (not to be confused with longitudinal bowing or springing of the axis of the roll) will set a limit to the thinness of the product, no matter how hard the rolls are screwed down. Since small-diameter rolls give a contact much more closely approximating to the theoretical line contact, even under deformed conditions, they will give a harder "bite" not only with a lower pressure but with considerably less rolling torque. This is illustrated by comparative figures given by A. I. Nussbaum* for the single-pass reduction of commercially pure titanium strip from 0.015 to 0.012 in., with 8-in. diameter and 2-in. diameter work rolls. Loadings were respectively 202,000 lb. and 49,000 lb.; rolling torques 65,000 in.-lb. and 975 in.-lb. per roll.

Naturally, with small-diameter rolls, the longitudinal deformation would become a limiting feature, and it is essential to provide back-up rolls of large diameter to prevent this.

*Stanat Manufacturing Co.

To sum up, for precision rolling of very thin strip, a 4-high mill with small-diameter work rolls is essential, and for breaking-down slabs or ingots, "skin-pass" rolling of annealed strip and mirror finishing of comparatively thick strip, a 2-high mill with large work rolls is preferable.

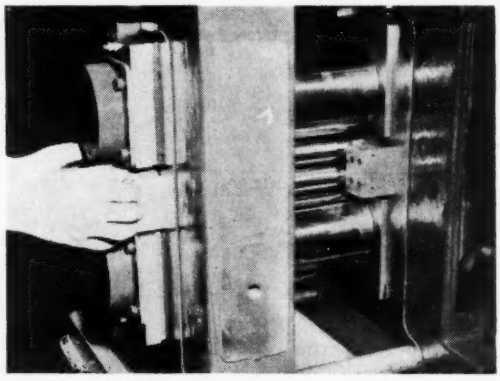
The Combination Mill

The introduction some two or three years ago of the Stanat-Mann mill provided a combination of both types in a single precision unit. Originally designed by Stanat Manufacturing Co., of Long Island, New York, it is manufactured in this country by Albert Mann's Engineering Co. Ltd., of Basildon, Essex, to whom we are indebted for information contained in this article. Their 2-high/4-high mill can be regarded as a 2-high mill with provision for inserting small-diameter work rolls or as a 4-high mill with driven back-up rolls which can be changed to a conventional 2-high mill. The change is rapid, it being merely necessary to insert or remove a single assembly, after operating the screw-downs.

A number of work-roll assemblies can be provided, so that it is a comparatively simple matter to change from one diameter to another, from flat rolls to crowned, or from steel to tungsten carbide which, having a modulus of elasticity about twice that of steel, reduces roll flattening to an absolute minimum.

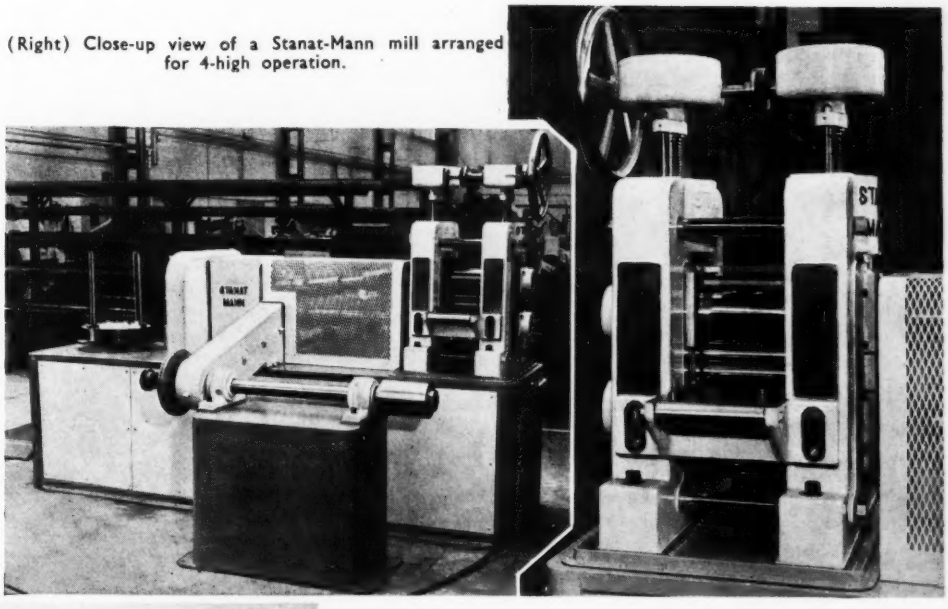
A further advantage of the small work roll is that it has less tendency to expand the strip sideways, thus reducing the cracking and tearing that might otherwise occur. Yet another advantage is that, since the drive is provided from the back-up rolls via friction, the power input to the mill is not limited by excessive stresses in the comparatively small necks of the work rolls.

It is necessary for a machine of this type to be a precision job throughout. When one considers that the finished material may be 0.0005 in. thick, it is obvious that there is no room for error due to lack of stiffness in construction or slop in the bearings or housings, and, from a critical examination, the Stanat-Mann mill possesses many features expressly designed to prevent any of these. Stiffness is assured by large-diameter roll necks, by cast housings of adequate cross-section and by generous designs of rolls, roll necks and universal drive shafts. Accuracy is ensured by hand-scraping of housings and grinding of chocks, and by the design of the bearings themselves. These are of the needle roller type, the needles being retained parallel to the axis of the roller by cages, thus ensuring greater accuracy than with the loosely-inserted races more commonly used, where the needles are liable to misalignment. The actual roll neck, hardened and ground, forms the journal of the bearing, eliminating clearances customary with push-fit inner races. Individual screw-downs, calibrated to 0.0001 in., assist in maintaining close tolerances on the finished product.

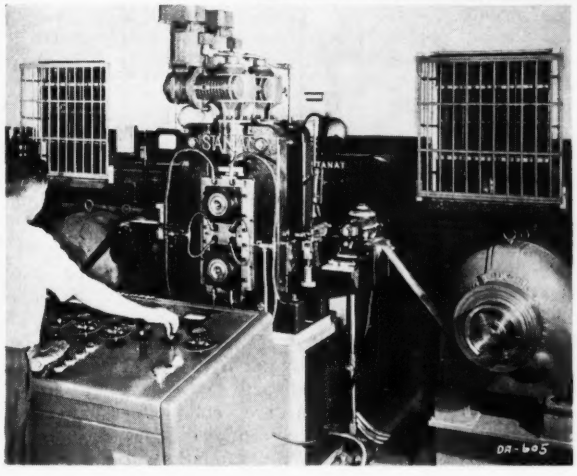


Removing roll assembly to convert from 4-high to 2-high mill.

(Right) Close-up view of a Stanat-Mann mill arranged for 4-high operation.



(Right) A complete mill unit, showing coiler operated from the main roll drives.



(Left) A Stanat (U.S.) mill with individual motor-driven coiler and motor-operated screw-downs.

For normal work, accessories such as tension coilers, edge rolls and edge trimmers can be supplied, while rolls can be supplied either flat or grooved for processing round, square or other sections. Heating or cooling of the rolls is frequently arranged. Sizes available utilize back-up rolls of 5 in. diameter × 8 in.; 8 in. diameter × 8 in. and 10 in.; and 10 in. diameter × 14 in. The small-diameter work rolls vary from $\frac{7}{8}$ in. diameter up to $2\frac{1}{2}$ in. diameter.

Drive

The type of drive provided can be varied to suit the particular application and the speed range required, and the motors vary from squirrel-cage induction, either with or without gearbox, and A.C. commutator motors to D.C. motors with Ward-Leonard control where a very wide speed range is required. Albert Mann's Engineering Co. Ltd. supply a control unit of their own where high-precision speed control is required. This is, in effect, an electronic speed regulator applied to Ward-Leonard control. In addition to the normal Ward-Leonard advantages of wide speed range and easy control, the electronic system provides stabilized speed conditions within very fine limits (0.1% of the pre-set speed from no load to full load) as well as controlled acceleration and deceleration and high-speed emergency braking.

Production machines for long lengths of strip are provided with coilers. These may be driven from the rolls, or separately motor-driven by motors synchronized with the mill motor, examples of both types being shown on this page. Screw-downs can be hand-operated or motor-driven: the lower illustration on this page shows a unit with motor-driven screw-downs using two 1-h.p. motors, thus retaining the ability to carry out individual adjustments.

Nuclear Applications

As may easily be imagined, the Stanat-Mann mill can be an exceedingly useful "work horse" for general service in nuclear research laboratories, and units have already been supplied to a number of manufacturing companies in the U.S. interested in atomic energy, including Babcock and Wilcox, the Dow Chemical Co., Thompson Products Inc. and G.E.C., and a number of A.E.C. projects including two for Hanford and four for the Argonne National Laboratory.

The United Kingdom Atomic Energy Authority and the Centre d'Etudes pour les Applications de l'Energie Nucleaire of Brussels have ordered mills from Albert Mann's Engineering Co. Ltd., and a further unit is being constructed by Stanat for the Junta d'Energia Nuclear, Spain. Mills are under construction to utilize complete "glove-box" techniques, and will operate in inert atmospheres. A most elaborate remote control and instrumentation system has been designed, and it will not only be possible to operate the rolls and screw-downs under "glove-box" conditions, but also to change the various types of roll, and from 2-high to 4-high, with rolls selected at will from four different sets.

Handling gear for the small specimens to be processed is another feature of the design, as is the inclusion of a comprehensive system of strain gauge instrumentation for indicating and recording torques and roll pressures.

It is anticipated that units of this type will be completed within the next six to eight months, when it is hoped to be able to publish further details which, at the moment, cannot be released.

A 5-W Laboratory Reactor

New American Design for Technical Colleges and Medical Schools

A MINIATURE research reactor which is small enough for educational, industrial or medical laboratories has been designed by Atomics International, a division of North American Aviation Inc. Intended to sell at about £20,000, it is, nevertheless, capable of a wide range of studies in the engineering, biological and medical fields and, according to information received, requires very little space and no special facilities or services, so that it could be installed in an existing laboratory.

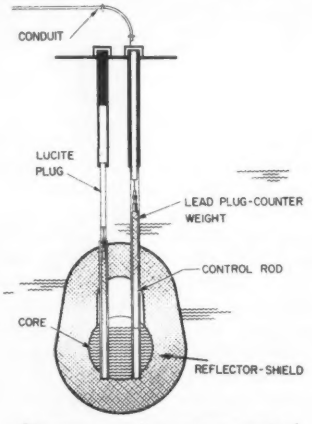


Diagram showing arrangement of core shielding and control rods.

In certain respects this reactor is a smaller and considerably simplified version of the private research reactor built by the same company for the Armour Research Foundation in Chicago (*Nuclear Engineering*, August, 1956, p. 198). Since, however, the nominal rating of the laboratory reactor is one ten-thousandth part of that of the Armour Foundation unit (5 W as against 50 kW), the construction is very much simpler, there being no external cooling or heavy concrete shielding, while gas recombination does not present the same problems.

The L.R. is of the homogeneous type, using a solution of enriched uranyl sulphate in water. The core is a stainless steel sphere about 12 in. in diameter, containing about four gallons of solution. Exposure tubes extend through the core, as do the vertical tubes for the control and safety rods.

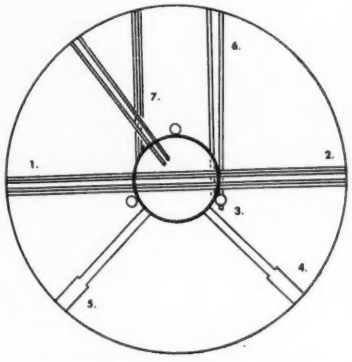
Above the sphere is a hemispherical canopy, which acts as a recombination chamber for the gases evolved and as a temporary overflow. Tubes for fuel filling and draining are attached to the core and gas tubes to the canopy.

The core sphere and canopy are enclosed in a lead shield 6 in. thick, serving both as a primary shield and as a reflector. This, again, is enclosed in an aluminium container approximately 24 in. maximum diameter and 2 ft. 8 in. high. The complete assembly is slung from three steel tubes in a tank of water, which serves as the neutron shield and as a secondary enclosure for the fluid. The tank is 8 ft. in diameter and 8 ft. high, and its enclosure provides a terminal point for the tubes going through and near the core, and for the sleeves for the control rods.

Control-rod System

The control rods are of cadmium, and are 10 in. in length, with a 10-in. travel, being located in the overflow canopy in their fully withdrawn position. Lead end pieces provide continuity of the shielding when the rods are raised during operation.

Raising and lowering of the rods is by flexible cables driven by electric motors, an electromagnet attachment being used between rod and cable for use in a "scram" shut-down. The motors driving the rods are under manual control, but their switches are interlocked so that, although both may be simultaneously inserted, only one can be withdrawn at a time. Each rod controls about 1.8% reactivity and the rate of withdrawal corresponds to approximately 0.02% /sec.



Plan showing main facilities: 1, main exposure tube; 2, auxiliary exposure tubes; 3, vertical supporting pipes; 4, neutron beam tube; 5, gamma-ray beam tube; 6, detector tube; 7, radioactive gas lines; 8 (optional), thermal column.

Fuel and Gas Handling

The core unit can be filled and drained without disturbing the shielding tank. From the underside of the core unit a remote-controlled valve is connected to a fuel line terminating in a mixing bowl on the outside of the tank, while a second line leads outside the tank to permit the solution to be drained by gravity.

The radioactive gases given off during operation are completely contained within the canopy above the sphere, in which recombination of the hydrogen and oxygen is carried out, the catalyst taking the form of platinized alumina pellets in a cylindrical screen

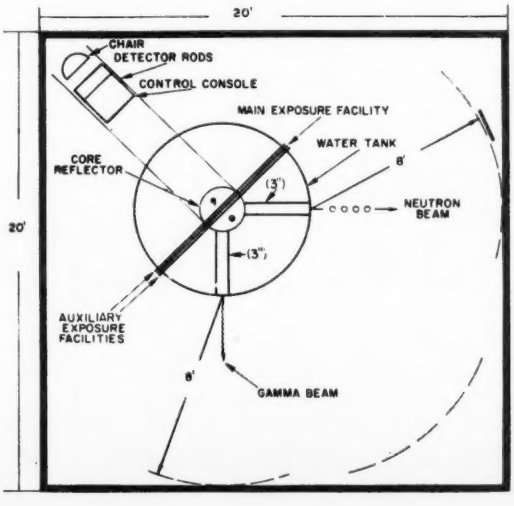
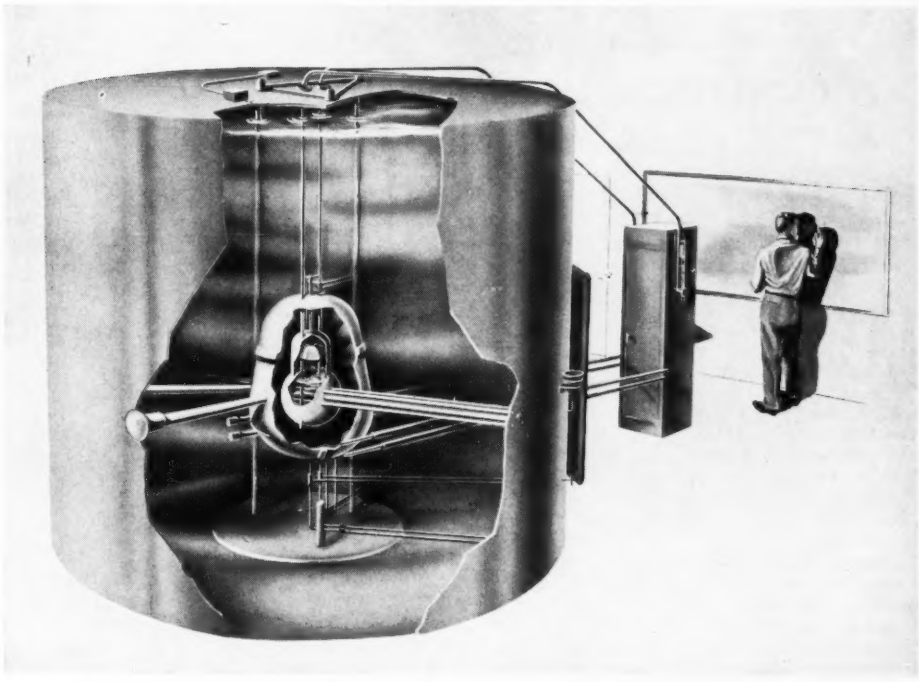


Diagram showing space requirements for existing laboratory.



Cut-away drawing, showing the general arrangement of the complete reactor and control console.

container, drying of the pellets being by a built-in resistance heater. The canopy is provided with two gas lines so that the gases can be withdrawn for experimental purposes, the activity produced during routine equilibrium operation being about 5 curies.

Instrumentation

All instrumentation is located at a console adjacent to the tank, control being by a single operator. Three boron-lined neutron counters are installed in the detector tubes through the tank. The counters are attached to wooden rods 9 ft. 6 in. long to enable their positions to be adjusted from the console. Located near the core at starting, they can be withdrawn as the power level increases, position stops indicating the scale changes which must be made in observing their associated instruments. The rate circuits are adjusted to provide one 2-sec. channel, primarily intended for accurate power recording, and two $\frac{1}{4}$-sec. channels intended for safety and observation. One of the fast channels includes a period circuit, and the slow channel operates a linear recorder. All three detectors are energized by a common high-voltage supply.

Interlocking is provided so that reactor operation is prevented from starting or shut-down if excess power is shown by any of the detector channels, or any channel shows a lower power level than normal. This latter guards against failure of any of the detector circuits or removal of the background source from its proper location for start-up. Interlocks also guard against low water level, short doubling time due to excess reactivity, low water level, A.C. power failure or high gas pressure.

Facilities

The experimental facilities are shown in plan on the accompanying diagram. Main and auxiliary exposure tubes are carried right through the core, pneumatic transfer being possible if required. The three vertical support pipes may be used as extra experimental facilities. If required, a thermal column 4 ft. square can be arranged.

Capabilities

The general particulars of the L.R. are as shown in the accompanying table.

It is stated that the L.R. will permit quantitative analysis for many elements by the neutron-activation method with an accuracy of 10 p.p.m. In addition, it is pointed out that more than 100 isotopes can be produced in this reactor, and from that point of view it can be an exceedingly convenient source of short-lived isotopes. It can thus contribute to the safety and convenience of the use of isotopes by permitting work to be carried out using short-life materials which can be disposed of by natural decay, but by the very fact of their short life cannot normally be used unless they can be made on the spot.

It also is stated that a wide range of biological research can be performed, including such work as genetic mutation studies and tracer research on plants and animals.

Reactor Characteristics

Power level	5 W
Core thermal neutron flux, n/cm^2-sec.	1.7×10^8
Beam tube fast neutron flux (approx.), n/cm^2-sec.	5×10^4
Beam tube thermal neutron flux (approx.), n/cm^2-sec.	5×10^5
Gamma ray beam, cm^2/sec. flux, γ/cm^2-sec. ...	10^6
Maximum gamma dose rate (in core), r/hr. ...	1,000
Fuel	Enriched uranyl sulphate solution
Fuel critical mass (approx.), gr. U 235	1,000-1,500
Shielding	Lead and water
Cooling	Water, natural convection

correspondence

Insurance Premiums

Sir,

We notice that in your July number life assurance offices are criticized for charging excessive additional premiums on account of occupational hazards in respect of workers in the atomic energy field.

We should like to draw your attention to the fact that this office makes no additional charge for occupation in respect of persons occupied at atomic energy research stations on work involving radioactive materials, since we feel that the precautions taken are such that any risk of excessive radiation can be ignored.

We cannot yet feel certain that persons working with radioactive substances in industries outside the control of the United Kingdom Atomic Energy Authority do not incur any extra risks and such cases are treated on their merits. We would say, however, that scientists and research workers employed by the largest industrial concerns would very probably be treated in the same way as those employed by the United Kingdom Atomic Energy Authority.

E. H. Potter,
The Northern Assurance Co. Ltd.

Sir,

There are many Life Offices who offer life assurance without extra rate of premium to persons employed by the Atomic Energy Authority, subject, of course, to their being in normal good health. The editorial "Atomic Energy Insurance", which appeared in the July issue of *Nuclear Engineering*, is therefore somewhat behind the times when it refers to an extra premium of 10/- per cent.

Secretary,
The Life Offices' Association.

Sir,

At the present time this Society is prepared to issue ordinary whole-life and endowment assurances on the lives of persons engaged in atomic energy work without charging any extra premium on account of the occupational hazard, irrespective of whether the life to be assured is employed by the U.K. Atomic Energy Authority or by industry.

In the past we did charge an extra premium to cover atomic energy risks, and if application is made for the removal of an extra premium the question is one for individual consideration. If an extra premium is removed, it is done purely as a concession by the Society. I would add that we are in a somewhat inequitable position in that because the risks have supposedly been lighter than anticipated we are asked to remove the extra premium; but on the other hand, had the risks become greater, we would have had no remedy, as we would be precluded from increasing the extra premium under an existing policy.

Whether there would be any advantage to be gained by converting an existing policy to paid-up would depend on the circumstances, such as the basic rate of premium and how long the policy had been in force.

Atomic energy risks are long term and nobody knows what the ultimate effects on mortality will be.

G. W. Bridge,
Legal and General Assurance Society Ltd.

The A.M.F.-Mitchell Reactor

Sir,

It was gratifying to read that my article on the A.M.F.-Mitchell reactor, which appeared in the July issue, had interested your correspondent, Mr. A. S. Robinson. Admittedly, it gave no clear indication of the actual status of the project, but it was intended to illustrate, in a general way only, the fundamental simplicity and safety of the system.

Your correspondent asks what arrangements are being made for the construction of an actual prototype reactor. The answer is that a prototype has been in operation for several years. Efforts are now being concentrated on the completion of design and manufacturing details of A.M.F.-Mitchell reactors for actual power production on a commercial basis. The first plant, which is being supplied under a contract received several months ago, will have an electrical output of 20 MW and is due to begin operation early in 1959. Although this is a comparatively small unit, operating at a medium steam pressure, the cost of electrical energy from this plant is guaranteed to be not more than 0.7d. per kWh.

As regards the capital cost of an A.M.F.-Mitchell reactor, this will vary according to the required function of the plant—i.e., whether it is needed for power production or for the supply of steam to an industrial process—and according to steam output, operating pressure, site conditions, etc.

The U 235, in a core of medium power output, is about 60 kg, 80% of this being contained in the natural uranium elements. The average U 235 in the core is somewhat less than 1%.

So far as the consequences of a serious fuel-element failure are concerned, it can safely be stated that they would in no way constitute a danger to operating personnel. From the point of view of plant availability, a failure would necessitate the immediate shutting down of the plant. The system would also require to be "cleaned up"; that is, flushed through with water, after the removal of the damaged element. The level of activity at the heat exchanger would not be unduly increased by a fuel-element failure.

The fuel-element handling system is intended to be extremely simple. It is considered best, however, that the addition of new elements to a core should be supervised by an expert, to ensure that the "approach to critical" is properly performed.

A monitoring device is located at a certain point in the reactor water-purification loop for the detection of faulty fuel elements.

H. J. Coles,
Mitchell Engineering Ltd.

FORTHCOMING EXHIBITIONS

1956			
PARIS:	**Chemical Industry, Rubber and Plastics Exhibition. November 21-December 3.**	**LONDON:**	**6th Electrical Engineers' Exhibition. April 9-13.**
NEW YORK:	**3rd International Automation Exhibition. November 26-30.**	**LYONS:**	**39th International Trade Fair. April 27-May 6.**
CLEVELAND:	**National Chemical Exhibition. November 27-30.**	**BRUSSELS:**	**31st International Trade Fair. April 27-May 12.**
1957		**BIRMINGHAM:**	**British Industries Fair. May 6-17.**
PHILADELPHIA:	**International Atomic Exposition and Nuclear Congress. March 11-15.**	**LONDON:**	**Instruments, Electronics and Automation Exhibition. May 7-17.**
COPENHAGEN:	**11th International Fair (Technical Section). March 19-27.**	**PARIS:**	**47th International Trade Fair. May 25-June 10.**
LONDON:	**Physical Society Exhibition of Scientific Instruments and Apparatus. March 25-28.**	**LONDON:**	**21st Engineering, Marine and Welding and Nuclear Energy Exhibition. August 29-September 12.**
LOS ANGELES:	**Western Metal Congress and Exhibition. March 25-29.**	**CHICAGO:**	**2nd Word Metallurgical Congress and 39th National Metal Congress and Exposition. November 2-8.**
		NEW YORK:	**26th Chemical Industries Exposition. December 2-6.**

World News

A meeting at the United Nations headquarters of the committee appointed to advise on atomic affairs. It is recommended that the Second U.N. "Atoms for Peace" conference shall be held in September, 1958.

UNITED KINGDOM

Dounreay generating plant. A contract covering turbo-alternator plant for the Dounreay reactor has been placed with the General Electric Co. Ltd. The set, of 15 MW capacity, will operate initially with steam conditions of 150 p.s.i. and 518°F. It will be built at the Fraser and Chalmers Engineering Works at Erith, Kent.

Lido in operation. Lido, the swimming-pool research reactor at Harwell, became critical on the night of September 20.

Hunterston, West Kilbride, on the Ayrshire coast, is now named in an application as the proposed site for the South of Scotland Electricity Board's nuclear station, thus confirming an earlier anticipation that this site was under consideration. Two reactors are visualized, with a total output of 250-300 MW. It is expected that the first reactor will be in operation by 1961.

Dounreay fuel-element cans. A contract has been placed with Accles and Pollock Ltd., a member of the T.I. group, for the Dounreay fuel-element sheaths. This will involve producing niobium and vanadium tubes to extremely fine tolerances and it is believed that this is the first occasion of the fabrication of these metals other than on an experimental basis.

Boron-10 manufacture is now proceeding in an isotope-separation column manufactured by 20th Century Electronics Ltd. in conjunction with the A.E.A. It is claimed to be the first commercially-produced column of its kind in the world.

Dounreay Technical College. According to the Scottish Amalgamated Trade News Agency, Caithness Education Committee is considering the construction of a technical college at Dounreay to meet the growing needs of the atomic energy project there and the training of North of Scotland apprentices and students in nuclear-engineering subjects.

AUSTRALIA

Mary Kathleen finance. According to the *Financial Times*, the U.K.A.E.A. has lent more than £6 million for the development of the Mary Kathleen uranium deposits in North Queensland. A report of an A.E.A. contract for £40 million worth of UO_2 confirms an earlier report (*Nuclear Engineering*, May, 1956) that such an agreement existed.

Atomic Plant for South Australia? Sites for new power stations in South Australia to follow the Port Augusta scheme are being investigated, according to an Adelaide report. It is possible that one of these may be an atomic plant, the other being of the conventional coal-burning type, like Port Augusta "B" which is scheduled for completion in 1962.

BULGARIA

Tass reports that the new Bulgarian atomic research institute is nearing completion near Sofia. The reactor has been supplied by the U.S.S.R.

CANADA

British turbo plant. The Des Joachims nuclear power station, to be constructed on the Ottawa river, will use British turbo plant. The contract has been placed with Metropolitan-Vickers Electrical Co. Ltd. for a 20-MW, 3,600-r.p.m. set operating at 400 lb./sq. in. dry saturated steam.

EUROPE

Agricultural mission. Under the auspices of the European Productivity Agency, a mission will arrive in the U.S. in March, 1957, to study atomic energy in agriculture.

FRANCE

Business Men's Courses. Courses in nuclear energy for non-technical executives in industry and business are being sponsored by a group of U.S. companies, it is stated, to encourage applications of peaceful uses of atomic energy. The courses will commence next January and will be held in Paris.

Marcoule reactor operating. Electricity was generated from the Marcoule station on September 28.

Uranium deposits. Prospectors of the French Atomic Energy Commissariat have discovered deposits of uranium at Malville, near St. Nazaire.

GERMANY

New Minister for Atomic Affairs. In the reshuffle of the German Cabinet it was recently announced that Herr Balke will take over the position of Minister of Atomic Affairs from January, 1957. Herr Strauss will, it is understood, continue to act as Minister until that date.

Munich University courses. The Bavarian State Government recently introduced a four-month atomic course at Munich University, covering the most modern methods of handling radioactive material and detecting and treating radiation diseases.

Protective clothing. A Reuter report from Heidelberg states that protective clothing recently developed will protect against atomic, bacterial and chemical weapons. Consisting of a plastic undersuit, gloves and boots, with a glass fibre outer covering, it is claimed that the suit will withstand temperatures higher than 1,000°C.

Uranium deposits. Ore deposits are said to have been discovered in the Rodhaar Mountains near Kassel, West Germany, and may yield up to 3.6% uranium. This compares with the 0.5% obtainable from ores from the only other known deposit in West Germany, the Fichdelgebirge mines.

HOLLAND

International exhibition. An international exhibition on the atom is to be held in Amsterdam next June. A swimming-pool-type reactor, built by A.M.F. Atomics Inc., will form part of the exhibition and will later be used elsewhere as a research unit. Operating at 10 kW, the reactor will be generally similar to that shown on the U.S. exhibit at the Geneva Conference.

HUNGARY

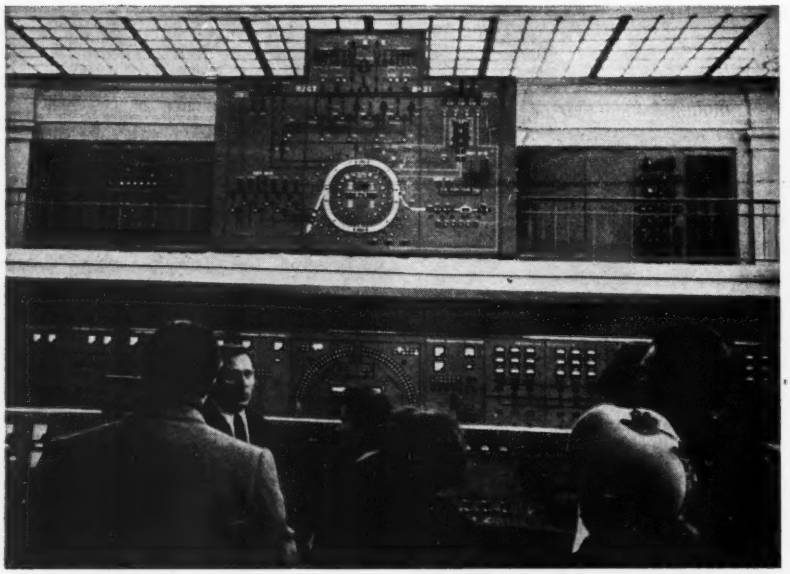
Construction of first reactor. Materials for Hungary's first nuclear reactor commenced arriving from Russia.

INDIA

Heavy water. Production of heavy water at the Nangal fertilizer plant now under construction is expected to commence by 1960, according to the *Times of India*. Investigations have also been going on into the possibility of manufacturing heavy water at Sindri fertilizer plant.

ITALY

A new company known as Sorin (Societa Richerche Impianti Nucleari) has been set up in Milan by Fiat and Montecatini for experimental nuclear power plant work.



European journalists in the control room of the accelerator of the Dubna Research Institute. Facing the camera is Valentin Petukhov, head of the Institute.

U.S.A.

Indian Point superheater. A contract has been placed with the Foster Wheeler Corporation of New York for a separate oil-fired superheater at the Indian Point plant being built by Consolidated Edison, the reactor steam being superheated to a final temperature of 1,000°F from 450°F. The contract figure named is more than $3 million.

Nuclear-powered cruiser. The Bethlehem Steel Co. has had instructions from the U.S. Navy to proceed with a 14,000-ton nuclear-powered cruiser, as yet unnamed. The reactor plant is under construction by the Westinghouse organization. Estimated cost of the ship is over £31 million.

The synchrotron at Pasadena (California Institute of Technology) has achieved electron acceleration to within 324 miles/sec. of the speed of light, it is stated.

Spent nuclear-fuel elements. A limited quantity of spent nuclear-fuel elements can be made available by the A.E.C. to industry needing gamma radiation for research and development purposes. The charge is $100 a year.

Oak Ridge National Laboratory has completed ten years of isotope production and distribution, which now extends to 57 countries.

Six submarine reactors and their associated equipment have been ordered from Westinghouse Electric Corporation at a cost of nearly £8¼ million.

Private inventions encouraged. According to a Reuter report, the A.E.C. plans to waive its rights to private inventions or discoveries resulting from materials it has supplied to industry.

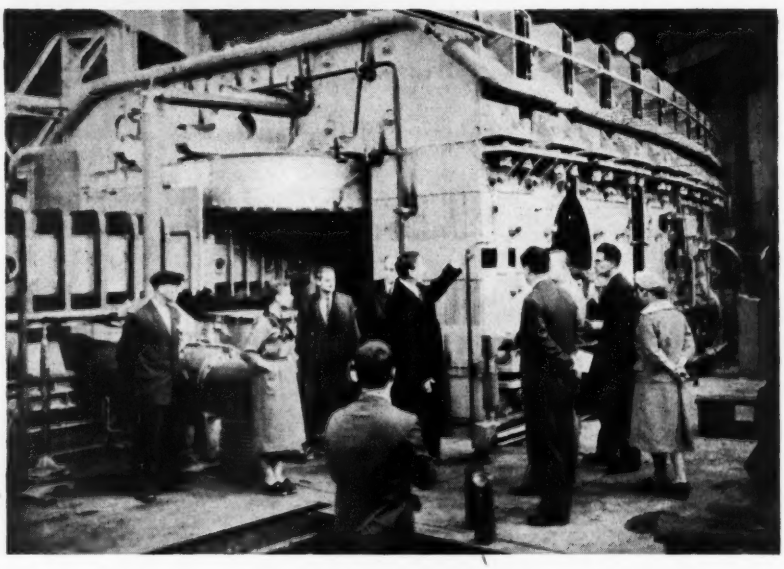
Beryllium Supplies for the A.E.C. Correcting a previous report that the Brush Beryllium Corporation was the only industrial producer of reactor grade beryllium, it is now announced that a duplicate contract for 250 tons has been placed by the A.E.C. with the Beryllium Corporation of Reading, Pa., who are represented in the U.K. by the Beryllium Smelting Co. Ltd.

Research contracts. Contracts with universities and private research institutions for 88 physical research projects have been placed by the A.E.C., 25 being new contracts.

Army Ionizing Centre. Eleven proposals have been received by the A.E.C. from industrial firms to participate in the design of a reactor to provide intense gamma radiation for food irradiation at the Army Ionizing Radiation Centre.

S.R.E. and O.M.R.E. A two-day classified conference is being held by the A.E.C. for access-permit holders and Commission contractors on the S.R.E. (Sodium Reactor Experiment) and the O.M.R.E. (Organic-Moderated Reactor Experiment). The S.R.E., now nearing completion in the Santa Susana Mountains near Los Angeles, is the graphite-moderated, sodium-cooled reactor which will drive a 7.5-MW turbine alternator operated by Southern California Edison at no cost to the U.S. Government. The O.M.R.E., on which construction has begun at the National Reactor Testing Station at Idaho Falls, uses a hydrocarbon (diphenyl) as a coolant and moderator. It is expected to be operating early in 1957. Both projects are being constructed by Atomics International Inc.

Pasadena's proposed reactor. The municipal light and power department of Pasadena has made a preliminary study for a boiling-water reactor with separately-fired superheater of 40-60 MW capacity.



European journalists being shown the 36,000-ton electromagnet system of the accelerator at the Dubna Research Institute, Valentin Petukhov, the head of the Institute, can be seen in the centre (dark overcoat).

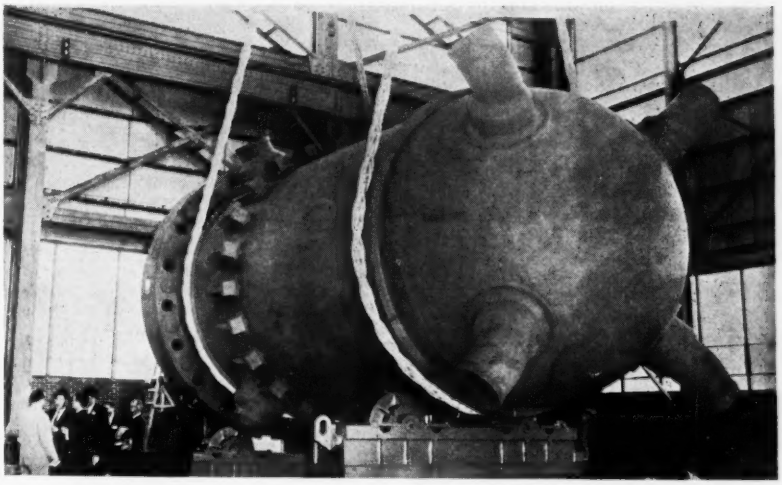
U.S.S.R.

Dubna research centre. The Joint Nuclear Research Institute at Dubna on the Volga river, 95 miles north-east of Moscow, is now in operation. Formerly operated by the Soviet Union, it is now under the joint sponsorship of Russia and 11 other Communist countries. According to a Reuter report, the Institute has cost 500 million roubles (£45,450,000 sterling) and employs some 1,200 persons. It is said that an experimental reactor using enriched uranium will be in operation by the end of 1957. The synchro-cyclotron, which is due for completion in the middle of 1957, is said to be the largest in the world, being rated at 10,000 MeV.

Orbits in Industry

Exhibitions seem to have been in the news during the last month, which started with the Fuel Efficiency Exhibition in full swing. It is fatally easy for those in the nuclear field to look at conventional fuels in the same way as the airline operator looks at the horse—why bother with improving the breeding of something that is already obsolescent?—and it is an attitude of mind that one has to fight against. Our contribution to the national economy is, at the moment, inconsiderable; we are going to do great things—sooner than many imagine—but economy in coal and oil will be of vital importance for many years to come. Nevertheless, to use an Irishism, the direct interest of most exhibitions to our industry is an indirect one. In other words, we are not so interested in standard products as in their possible adaptations. The connection between, say, oil-fired equipment and nuclear engineering may seem a little tenuous, for example, but oil-fired superheaters are going to be a part of our scheme of things for some time to come if maximum efficiency is going to be obtained from the steam cycle.

Even more interesting, however, is the application of special techniques. The nuclear field would start at a very big disadvantage if, for example, the boiler manufacturers had not had many years' experience in building equipment without leaks. It was not so many years ago that it was quite a problem to expand a tube into a thick drum so that high pressures did not tend to force it out again. A new industry has to evolve its techniques from those of older industries: looking round the Fuel Efficiency Exhibition, one realizes that nuclear engineering is fortunate in having such a vast range of special skills to draw upon.



A 235-ton reactor vessel, built by Combustion Engineering Inc. for the Shippingport reactor, about to be dispatched.

E.I.A.

Even in the most unexpected places one comes across items that are of intense interest to our industry, although, once again, the connection may seem fairly remote. One sees a blowlamp operated by a butane gas cylinder and, mildly interested (thinking of one's own paraffin blowlamp that decided to have a fit of hiccoughs when surrounded by inflammable material), inquires further, only to find of course, that the same company's butane-heated soldering iron is being used in large quantities on the Dounreay site as being the only thing so far discovered that will stay hot in the bitter winter weather. Furthermore, that the same company makes leak detectors—you see the way it goes? This actually happened, by the way, at the Engineering Industries Association Exhibition, the ninth London regional display. A great little bunch, the E.I.A. One does not hear a great deal of their doings, but they perform yeoman service for their members. When materials were so short after the war, many of the smaller companies must have been more than grateful for the way in which the Association rapidly made known requirements amongst their members and put the manufacturer who *had* to have 3 ft. of hexagonal brass $2\frac{7}{16}$ across flats in touch with the one manufacturer who happened to have it left over from a contract five years earlier.

Flash-back

In addition to these two exhibitions, the Council of Management of the Electrical Engineers Exhibition recently gave a showing of the film of their fifth exhibition, which took place in March. It is interesting to speculate on how many people remember the first. Seldom can any exhibition have risen so rapidly to become one of the most important events of the year from such modest beginnings. For the first occasion was a purely local affair organized by the North-west London branch of the Association of Supervising Electrical Engineers. Held in a church hall in South Harrow in 1950, for one night, it was attended by two representatives of the technical Press (one of whom, incidentally, was the present writer). Two men were chiefly responsible for the organization and one, "Bill" Brammer, is dead. The other, P. A. Thorogood, is very much alive, however, and has made good, in face of all opposition, his original intention to turn his idea into reality. Local show, to adapt a phrase, has indeed made good. Next year's exhibition will be larger than ever; in fact, the ground floor of Earls Court will no longer contain it.

Other Exhibitions

An exhibition of a different kind is the one opened by S.I.M.A. (Scientific Instrument Manufacturers' Association) at 20 Queen Anne Street, London, W.1. This is one of those semi-permanent exhibitions that fulfil a dual purpose: a London shop-window for those who have no permanent showroom and a centre for the overseas visitor who has not the time to tour the country calling on a number of companies.

Yet another type is the short-term "open days" held by the Government and similar establishments. One which has recently undertaken this is the Department of Scientific and Industrial Research, who threw open their mechanical engineering research laboratories at East Kilbride, near Glasgow, for the first time.

Finally, it was a matter for some regret that the space-time continuum prevented us attending the Trade Fair of the Atomic Industry which opened in New York in late September. Let us hope that this state of affairs will be remedied for the 1957 Nuclear Congress in Pennsylvania next March.

Possibly the most outstanding short-term exhibition, not of the month, but of the century, was the official opening of Calder Hall by H.M. the Queen. Most of those attending have been full of praise for the organization, which, it was generally felt, was first rate.

One of the most striking features of the whole day, however, was the interest displayed by the construction people in the exhibition marquee forming part of the tour. This contained, in addition to the A.E.A.'s exhibit from the Fuel Efficiency Exhibition, a scale model of Calder Hall itself; and the way in which all employed on the site, from ironfighters to painters, crowded in to see it left little doubt as to the efficiency of this type of exhibit as a form of employee-relations work. The idea of letting those responsible see the whole scheme, and where their own part fits in, has been tried out by many enlightened industrialists from time to time: the response at Calder is positive proof of the success of such a course.

Educational

The Sir John Cass College, Jewry Street, Aldgate, London, E.C.3, is arranging full-time courses on "Radio-isotopes and their

Uses" beginning on Monday, January 14, 1957. This differs rather from courses previously announced, not only in that it is full-time instead of evening classes but also in that it includes practical work. The course is to be repeated every term, being modified, if considered necessary, to suit the needs of those attending. Intended for engineers, physicists, chemists, biologists and medical practitioners, the course is restricted to graduates (or equivalent qualifications) and the number of places will be limited. The fee (£30) includes laboratory materials and loan of protective clothing for the four weeks' course.

A less-ambitious course is being organized by the Northern Polytechnic, Holloway Road, London, N.7, commencing on November 15 and consisting of four lectures. It is stated that facilities are available for students to undertake simple experiments involving the use of radioactive sources and counting equipment.

Bouquet for the B.B.C.

Bearing in mind the number of brickbats that the B.B.C. receives in the normal course of its labours, it seems only fair that the reverse should apply, and our small bunch of simple posies is shyly thrust forward in our hot little hand to record appreciation of "Science Survey". Those whose main interest in the nuclear field tends towards the heavy plumbing, nevertheless appreciate such items as Professor Frisch's recent talk on the neutrino. It was topical, it was understandable and it was informative. This series is always good, although, according to one's own particular interests, some subjects must appeal more than others. But the B.B.C. is really doing a very fine job here. It gets the right men, the right subjects and the right length—neither too short to learn anything, nor too long to keep the family quiet.

It is gratifying to see, also, that science provides the theme for the Reith lectures this year, Sir Edward Appleton being scheduled to speak on "Science and the Nation", the series starting on Sunday, November 11.

Changes of Address

Babcock and Wilcox Ltd. have now moved from Farringdon Street to their new premises in the Euston Road. Telephone number is now EUSton 4321.

Steels Engineering Installations Ltd. and Archibald Low and Sons Ltd. have now moved to 143 Sloane Street, London, S.W.1. Telephone SLOane 6178.

Conversation Piece

Scene: The Euston Hotel, prior to the departure of the Calder Hall train.

Dramatis Personæ: Three Distinguished Atomic Scientists, Lesser Lights, Members of the Public, Chorus of Rustics, etc.

(The three D.A.S.s are discovered engaged in conversation. Enter a Member of the Public, who addresses one of them, presenting book:)

M.O.P. (*shyly*). Could I have your autograph please?

D.A.S. (*gratified, but puzzled*). Why?

M.O.P. Well, you *are* Liberace, aren't you?

D.A.S. (*winded, but rallying gallantly*). WHO is Liberace?

SLOW CURTAIN.

Meetings to Note

November 5.—Society of Engineers: "Gas Turbines in Theory and Practice", D. F. Collins, Geological Society, Burlington House, London, W.

November 6.—Incorporated Plant Engineers (London, at the Royal Society of Arts): "The Use of Isotopes in Industry"', C. W. Jones.

November 8.—Incorporated Plant Engineers (Glasgow, at the Scottish Building Centre): "An Introduction to Atomic Energy", J. A. Dixon.

November 22-23.—B.N.E.C. Symposium on Calder Hall, Central Hall, Westminster.

November 22.—Institute of Marine Engineers, West Midlands Section: "Nuclear Engineering", J. A. Kendall, Birmingham Engineering Centre.

November 22.—Society of Instrument Technology, Newcastle Section: "Instrumentation of Nuclear Reactors", T. R. Thompson.

November 22. — Physical Society (Science Museum): "The Discovery of V-particles and the Properties of Hyperons", Professor G. D. Rochester and Dr. C. C. Butler.

November 28-30.—Exhibition by E.M.I. Electronics Ltd., Royal Hotel, Woburn Place, London, W.C.1. Tickets from E.M.I. Electronics Ltd., Hayes, Middlesex.

November 27.—Joint Nuclear Marine Propulsion Panel (Institute of Marine Engineers and Institution of Naval Architects, at 85 Minories, E.C.3): "Some Safety Considerations of Nuclear Power Reactors", C. D. Boadle.

Calder Hall Contracts

Second List

Note—Many of these were sub-contractors to Taylor Woodrow Ltd.

NEW WESTERN (ENGINEERING) LTD., 136 Meadow Lane, Leeds 11
Control desks and wiring.
20TH CENTURY ELECTRONICS LTD., New Addington, Surrey
Neutron counters.
ALEX FINDLAY AND CO. LTD., 52-54 High Holborn, London, W.C.1
Building and civil engineering.
WILLIAM BOBY AND CO. LTD., 23 High Street, Rickmansworth, Herts
Building and civil engineering.
HENRY R. AYTON LTD., 7 Brunswick Street, Belfast
Building and civil engineering.
F. LABBETT AND SONS LTD., Nottingham
Painting.
POLLOCK BROS. (LONDON) LTD., Liverpool
Plastering.
MANCHESTER SLATE CO. LTD., Manchester
Asbestos sheeting.
THE LIMMER AND TRINIDAD LAKE ASPHALTE CO. LTD., Manchester
Asphalte.
CONCRETE LTD., Stourton, Leeds
Precast concrete floors.
RUBEROID LTD., London
Steel deck roofing.
HILLS (WEST BROMWICH) LTD., West Bromwich
Patent glazing and metal windows.
PLASTONA LTD., Wimbledon, London
Granolithic floors.
TRIPLEWOODS LTD., Horley, Surrey
Metal partitions.
S. W. FARMER AND SONS LTD., London
Metal balustrading.
HASKINS ROLLING SHUTTERS, London, E.17
Rolling shutters.
F. HAYWORTH LTD., Ramsbottom, Manchester
Acid-resisting tiling.
COMMERCIAL MARBLE AND TILE LTD., Newcastle 2
Terrazzo floors.
J. THOW LTD., Ayr, Scotland
Glazing.
BORDER ENGINEERING CONTRACTORS LTD., Whitehaven and Carlisle
Tarmacadam road surfacing.
BRAMHALL ENGINEERING CO. LTD., Manchester
Control-room ceiling lighting panels.
SUPER WOOD PRODUCTS LTD., Burscough Town, Ormskirk, Lancs
Joinery and internal timber stacks to cooling towers.
MILNERS SAFE CO. LTD., Holborn, London
Safes.
OVERSTRUCTURES LTD., London
Tubular welded building framework.
THE YORKSHIRE PUBLIC WORKS CO. LTD., Hipperholme, Halifax
York stone paving.
ESKETT LIMESTONE QUARRIES LTD.
Aggregates.
NORTHUMBERLAND WHINSTONE CO. LTD.
Aggregates.
THOS. ARMSTRONG LTD.
Sand.
GEORGE CASSON
Sand.
EDENHALL CONCRETE PRODUCTS LTD.
Concrete common bricks.
BLACKBURN BRICK CO. LTD.
Engineering bricks.
BARKER AND JONES LTD.
Facing bricks.
CEMENT MARKETING CO. LTD.
Cement.
THOS. ARMSTRONG
Concrete fence posts.
SHAP GRANITE LTD.
Concrete fence posts.
JOSIAH PARKES AND SONS LTD., through Nettlefold and Moser Ltd.
Door locks.
NETTLEFOLD AND MOSER LTD.
Door furniture.
BRITISH TROLLEY TRACK CO. LTD.
Sliding-door gear.
HAYWARDS LTD.
Steel doors.
MATHER AND PLATT LTD.
Steel doors.
EXPANDITE LTD.
"Flexcell" expansion jointings.
UNIVERSAL ASBESTOS CO. LTD.
Asbestos pipework, etc., in cooling towers.
HAM, BAKER AND CO. LTD.
Cast-iron flush and sludge valves in cooling towers, and rectangular penstocks.
HOLLOWAY METAL ROOFS LTD.
Copper expansion strip.
NON-FERROUS DIE CASTING CO.
Aluminium-bronze gravity cast sprinklers.
C. PARRY
Special scaffolding and shuttering.
W. AND J. LEIGH LTD.
Paints.

Mr. A. Young

Mr. R. T. Outen.

Mr. B. Gray.

Mr. V. W. Dale.

Mr. W. A. Hartop.

Personal

Major-General C. A. L. Dunphie, C.B., C.B.E., D.S.O., a director of Vickers Ltd., has now been appointed managing director. He is chairman and managing director of Vickers-Armstrongs; chairman of Vickers-Armstrongs (Aircraft), Vickers-Armstrongs (Engineers) and Vickers-Armstrongs (Shipbuilders); and a director of a number of other companies within the Vickers group.

Mr. Roland T. Outen has been appointed chairman of the Fairey Aviation Co. He has been deputy chairman of the company for the past seven years.

Mr. V. W. Dale, Companion I.E.E., will relinquish his position as director and secretary of the Council of the British Electrical Development Association because of health considerations.

Mr. A. Young, resident engineer, Calder Works, is leaving the U.K.A.E.A. to take up an appointment with C. A. Parsons and Co. Ltd.

Mr. D. S. Woodley (chairman), **Mr. A. L. Ayton** (secretary) and **Mr. A. H. Woodley** will constitute the new board of Blackman Export Co. Ltd. which has now come under the management of Keith Blackman Ltd. **Mr. G. L. Copping,** A.M.I.Mech.E., M.I.H.V.E., has relinquished his directorship of Blackman Export Co. Ltd., but will remain with Keith Blackman Ltd. in a consultative capacity.

Mr. H. Chisholm, joint managing director of A. C. Cossor Ltd., has been appointed chairman of a new subsidiary, Cossor Communications Co. Ltd., which has been formed to extend the group's telecommunications interests. **Mr. T. S. Heftman** is general manager and technical director and **Mr. I. Campbell-Bruce** sales director.

Mr. J. W. Howlett has resigned from the office of chairman and managing director of Wellworthy Ltd., a subsidiary of Associated Engineering Holdings Ltd., but remains on the board. **Mr. A. J. Woolcott** becomes the new chairman and managing director.

Mr. W. H. Raye, Jr., vice-president of the First National Bank of Boston, has been elected a member of the board of directors of the National Research Corporation.

Mr. G. McOnie, director of Pilkington Ltd., has been elected honorary president of the Glasgow University Engineering Society for 1956-57.

Professor H. Burrow has been installed as chairman of council of the Royal Society of Health for the year 1956-57. He succeeds **Dr. Albert Parker,** C.B.E.

Sir Hugh Beaver has been elected deputy president of the Federation of British Industries. Sir Hugh is a vice-president of the British Institute of Management, a director of the Colonial Development Corporation and is on the board of Richard Thomas and Baldwins Ltd.

Mr. G. P. Davidson has been appointed head of the nuclear power plant activities of Head Wrightson and Co. Ltd. Mr. Davidson has been project and construction manager with the engineering division of the industrial side of the Distillers Co. Ltd.

Dr. Lewis R. Drake has taken over the position of assistant director of the Nuclear and Basic Research Laboratories of the Dow Chemical Co. Dr. Drake was formerly production control superintendent at the U.S. Atomic Energy Commission plant operated by the company. **Dr. Griffin D. Jones** has been elected a director of the company, succeeding **Dr. W. C. Bauman,** who has been made director of research of the company's chemicals department.

Mr. J. A. Hatchwell has been appointed director of the new government field service department of Allen B. Du Mont Laboratories Inc. The new department will provide government and military projects with field engineers for installation, maintenance, instruction, development and production of electronic equipment.

Mr. K. Priddy has been appointed exhibition manager of Beck and Pollitzer-Overseas-Ltd., which has been formed by Beck and Pollitzer-Contracts-Ltd. to provide a service catering for the needs of exhibitors abroad.

A presentation, subscribed by the past and present members of the Society of Instrument Technology, was made to **Dr. Harold Moore,** C.B.E., on September 25 on the occasion of his retirement from the honorary editorship of the Society's Transactions. The presentation was made by **Mr. A. J. Young,** B.A., B.Sc., president of the Society.

Mr. H. E. Vickers, A.M.I.Mech.E., M.I.E.E., generation engineer (operation), Yorkshire division of the C.E.A., has been appointed chief generation engineer (operation) of the South Western division.

Mr. R. J. C. Bryce has been appointed district manager of the Scottish division of British Oxygen Gases Ltd., and **Mr. A. Knowles,** manager of the Wembley works, has been appointed technical manager, Acetylene, at the company's headquarters. He takes over the position formerly held by **Mr. E. A. Groom,** who is taking up an appointment with the parent organization, the British Oxygen Co. Ltd., and is succeeded at Wembley by **Mr. D. R. Harris,** formerly assistant production manager at head office, British Oxygen Gases Ltd. **Dr. P. H. Sykes** has been appointed chairman of the new private company, British Oxygen Research & Development Ltd.; **Dr. N. Booth,** managing director, and **Dr. L. C. Bannister** will complete the board.

Wing Commander A. E. Dale has joined the Pulsometer Engineering Co. Ltd. to carry out liaison duties in connection with aircraft fuel-pump products.

Mr. R. Reiss and **Mr. H. Levesque** have been appointed assistant sales managers of Baird Associates-Atomic Instrument Co., Cambridge, Mass.

Mr. Robert W. Schumann has been appointed chief development engineer of Radiation Counter Laboratories, Illinois. Mr. Schumann was formerly with Argonne National Laboratories.

Mr. W. A. Hartop, works director of George Kent Ltd., is visiting Canada to review the present status and progress of the Kent manufacturing subsidiary there, Kent-Norlantic Ltd. The visit will last about a month and during that time Mr. Hartop will travel some 20,000 miles, calling at Toronto, Ottawa, Winnipeg, Montreal and Vancouver.

OBITUARIES

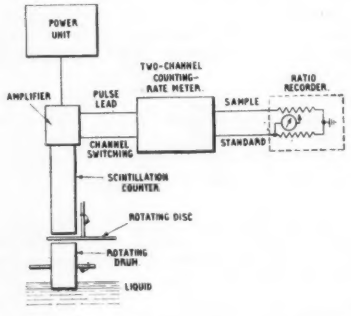
It is with regret that we have to announce the death of **Sir Richard Fairey,** M.B.E., Hon.F.R.Ae.S., Hon.F.I.Ae.S., founder and executive chairman of the Fairey Aviation Co. Ltd.

We also regret to announce the death, on October 7, of **Mr. B. Gray,** director of English Steel Corporation Ltd., only a week after his retirement. Mr. Gray was 68.

Technical Papers and Publications

The Measurement of Radioactivity *by Denis Taylor, M.Sc., Ph.D., M.I.E.E. (Chairman's address to the I.E.E. Measurement and Control Section).*

In a brief introduction to his subject, Dr. Taylor pointed out that it had once been the exclusive province of the physicist but was now equally the province of the electrical engineer. He then referred to the general principles of radiation detection and the possibility of measuring a small proportion of the radiation and calibrating in terms of the total emission. An instrument for the continuous monitoring of α-active material in solution, in the presence of β- and γ-active matter, was described as an example of the way in which a single unit could involve many fundamental problems. The scintillation counter (zinc sulphide with a photomultiplier tube) observes a representative sample of the liquid which is presented to it by a revolving drum dipping into the liquid. Between the drum and the scintillation counter is a rotating disc which presents alternately a window through which the radiation can pass freely and a standard radioactive source, so that the counter measures the process solution and the calibration source in rapid alternation. The amplified pulses are passed to a pulse-amplitude discriminator which permits only pulses above a definite threefold value to pass to the counting apparatus, a two-channel instrument switched in synchronism with the disc, so giving separate indications of the monitored solution and the standard source. A self-balancing potentiometric recorder gives continuous record of both activities and their ratio, thus revealing any tendency to drift in the standard.



Simplified diagram of counting equipment.

Although a very high degree of sensitivity could be achieved in the measurement of radioactivity, the ultimate sensitivity was affected by the background activity, i.e., that obtainable from stray radiation which could be quite large. Reduction of the background counting rate could be achieved by careful construction, using materials without any trace of radioactivity and by using further counters in an "anti-coincidence" circuit to cancel out stray radiation such as cosmic rays. Tenfold gains were possible by this means, the background rate being as low as one per minute. Where there was a choice it was better to measure α activity rather than β or γ; counters for particles could be made with a background of two counts/hr. In addition, an improvement of at least five times could be made by the use of pulse-amplitude analysers for selecting the energy range of the required emissions.

Measurements of body radioactivity were then described, it being pointed out that body radiation from its radioactive potassium content could be quite large compared with measurement required for, say, the assaying of radio-phosphorus. Body radiation measurements presented difficulties due to the large size of the source. Methods were described for shielding the chambers used in these measurements. High-pressure ionization chambers had been successfully used and scintillation counters had also given excellent results, the ultimate sensitivity being of the order of 5×10^{-10} curie. Sodium iodide was considered to be preferable as a scintillation material. The sensitivity of the A.E.R.E. apparatus was shown by the fact that when unshielded it would indicate whether BEPO—at a distance of several hundred yards—was in operation or not.

Measurement of fission rate was of prime importance in the running of a reactor. At high power levels (near maximum) heat output could be used for indication of fission rate, but this was useless at low or varying loads. The only practical method was to use neutron flux measurements at a particular position in or near the core, separate neutron flux measurements being made throughout the core for purposes of calibration. Two methods used in present control systems were an ionization chamber with D.C. amplifier, and a BF_3 proportional counter with a counting-rate meter for low power levels.

The effective neutron-γ sensitivity could be increased by the use of two ionization chambers, one sensitive to neutron-γ radiation and one to γ radiation only, connected in opposition.

In order to avoid radiation damage and high temperatures, the counters at Calder Hall were located outside the reactor core, and a neutron activation technique used for the flux distribution measurements for calibration. One such method used a tungsten wire stretched through the reactor and withdrawn after a specified irradiation time for flux measurements.

Conduction and Induction Pumps for Liquid Metals. *By L. R. Blake, Ph.D., B.Sc., A.M.I.E.E. (Paper read before the I.E.E. in conjunction with the B.N.E.C., October 25.)*

Electromagnetic liquid-metal pumps, utilizing the force produced in a conductor situated in a magnetic field and obeying Fleming's left-hand rule for motors, can be conveniently divided into two classes: *conduction* and *induction*. In the first class, the current is fed into the metal by actual contact with an outside source, such as electrodes in the tube walls; the chief disadvantages being the high current and consequent heavy busbars required. In the induction class, currents are induced within the metal from an external field, a convenient method being the use of a travelling field, as in an induction motor. Three main types of induction pump are recognized: the spiral, the flat linear and the annular linear, known for short as Sip, Flip and Alip. In the Sip type, guide vanes are provided to give a spiral motion.

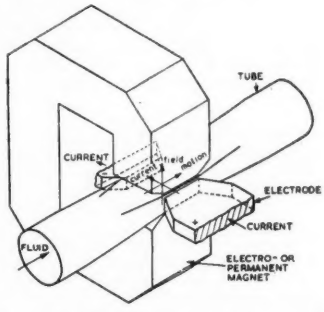


Fig. 1. Conduction pump in its simplest form.

The linear type has a flat winding arranged in a straight line, and the copper end rings used for Sip are replaced by side bars of copper fixed to the tube walls. In Alip, the winding takes the form of separate rings spaced along the tube and the metal travels through an annular space between the central core and the tube. There are other forms, such as a split winding arrangement, a cross between Flip and Alip; and a reverse-flow Alip in which the metal enters the pump by a pipe within the core and then reverses direction to flow through the annular space. Both these arrangements enable the windings to be removed without disturbing the pipe-work.

After dealing with the basic equations of electromagnetic pumps and the hydraulic losses, the paper considers the induction pump in greater detail, commencing with the design equations in an

ideal linear pump and proceeding to examine the various methods of grading the windings to obtain a practical approximation to the ideal condition of zero flux at the pump ends and the maximum in the middle. This is followed by a consideration of flux penetration effects and a description of an experimental Alip to give an output of 400-500 gal./min. at a pressure of 14/10 p.s.i.

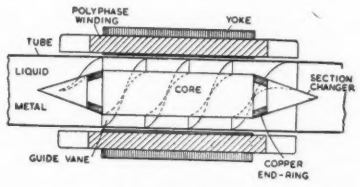


Fig. 2. Spiral induction pump (Sip).

The spiral induction pump is then considered, with particular reference to the effect of the axial component of the movement on pump performance.

Turning to the conduction pump, the ideal pump is first considered together with the modifications introduced by the effects of wall and end currents and of armature reactions, both of which, it is shown, are more pronounced with sodium than with bismuth. Compensation for reduction of armature effects can, it is shown, be reduced by the use of compensating windings.

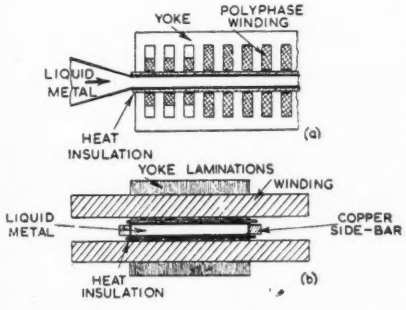


Fig. 3. Flat linear induction pump (Flip). (a) Longitudinal. (b) Transverse sections.

The A.C. conduction pump, it is stated, is even less susceptible to rigorous calculation than the D.C. unit, but most practical forms can be derived from the D.C. pump calculating eddy-current losses separately.

Summarizing the conclusions, the paper points out that different types of pump are complementary. The A.C. conduction pump is restricted to small power units, since eddy-current losses increase rapidly with size and, in spite of its advantages as regards current-supply difficulties, it is inferior to the D.C. pump with bismuth at high powers and with sodium to induction pumps, except in the very smallest sizes. The D.C. pump has the best performance figures of any pump at all levels with bismuth. Induction pumps are inefficient with bismuth except at very high powers, but with low-resistance fluids, such as sodium, Na-K and lithium, the spiral pump gives good performance, the linear pump being effective for the larger units. In comparing the two forms of linear pump, it is pointed out that the Alip has the advantages of a cylindrical

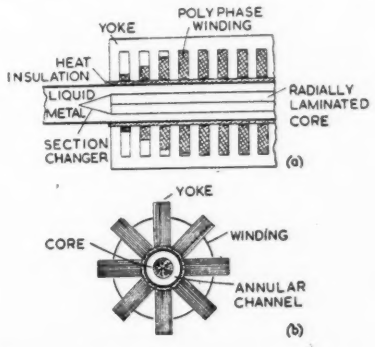


Fig. 4. Annular linear induction pump (Alip). (a) Longitudinal. (b) Transverse sections.

tube, thus withstanding pressure or vacuum more effectively and dispensing with electrodes which are a source of both eddy-current and ohmic losses. The winding is also simpler.

Acknowledgments are made to colleagues in the research department of the British Thomson-Houston Co. Ltd.

The Welding of Spheres and Bullets *in situ* *by M. J. Noone, M.I.Mec.E., and W.C.Holliday, B.Sc., A.M.I.Mech.E. (Paper read before the Institute of Welding's autumn meeting.)*

The fact that both authors are with Whessoe Ltd. and were concerned with the design and construction of the Calder Hall pressure vessel gives additional interest to this paper, which is primarily concerned with the design factors and special problems concerned with large vessels, and their materials, shop fabrication, erection and preparation, the ambient conditions, inspection, stress-relieving and methods of testing. There is some interesting information on the welding of austenitic steels; on materials for low-temperature service; on the methods of stress-relieving; and on the precautions necessary if air testing is to replace the conventional hydraulic methods. These include the use of notch-ductile steels, 100% X-ray examination of all butt welds, magnetic crack detection of important fillet welds, additional precautions in design and inspection, special precautions for safety of those engaged in the testing, and the use of strain gauges during the actual test operations.

The Problem of Liquid and Gaseous Effluent Disposal at Windscale *by F. R. Farmer, B.A. (B.N.E.C. paper read before the Institute of Civil Engineers.)*

This paper gives the experience of more than four years' work on the problem of effluent disposal, and shows that this is a major consideration in the preliminary design stages of any nuclear plant, affecting the type of reactor, the chemical processes involved and the site. At Windscale, the emission of radioactive gases has been held to one-tenth of the tolerance levels agreed by the International Commission for Radiological Protection. The discharge of liquid effluent, through a two-mile pipeline into the Irish Sea, has been shown to be harmless to fish, fishermen and bathers. More than 1,500 samples collected during a 14-month sampling programme with an average discharge of 50 c/day were analysed, including seaweed, fish, shore sand and sea-bed. The limit to the discharge appears to be the absorption of the active ruthenium 106 isotope by edible seaweed. In other respects, the activity levels are below the International Commission's recommendations by a factor of about 100.

Principles and Applications of Hydrodynamic-type Gas Bearings *by G. W. K. Ford, M.B.E., M.A., D. M. Harris, B.Sc., and D. Pantall. (Paper read before the Institution of Mechanical Engineers.)*

Bearings using gas in place of a liquid lubricant can be divided into two basic types: the hydrostatic, in which a definite gas pressure is maintained between the bearing surfaces by external means; and hydrodynamic or self-acting, in which the relative motion of the two elements provides the necessary hydrostatic pressure between the clearance space. The latter type has, of course, the advantages that no pumping power is required and, even more important, that there is no question of there being any exhaust gas to dispose of.

The difference between operation of a given bearing on oil or gas is a direct reflection of the relative viscosities of the two media and the capacity of a given bearing may, in theory, be more than 1,000 times greater when operated on oil. Nevertheless, in small machines bearings are often, for mechanical reasons, much larger than they would be for bearing performance only, and gas-operated journal bearings are compact enough to be practicable for small machines. For thrust bearings, the normal inclined-pad bearing is usually replaced by a pair of flat discs, one of which is covered with a pattern of spiral grooves.

The gas bearing shows considerable promise in locations where contamination by liquid lubricants is not acceptable or where radiation would cause deterioration of organic lubricants, and two practical designs for a CO_2 circulator and a liquid-metal cooling pump are shown. It would appear, however, that there are limitations imposed on bearing sizes, since static loads increase as the cube of linear dimensions, dynamic loads as the fourth power, and bearing strengths only as the square; but it is considered feasible to produce bearings of reasonable size up to 100 h.p. Experiments carried out have ranged from 1 to 7 in. diameter. The necessity for jacking air at starting will depend on circumstances such as stationary loads and starting torques available. There is, of course, a necessity for very fine finishes on bearing surfaces, and figures of 1 to 6 micro-in. are mentioned.

In general, it is considered that any gas that can be physically contained can be used to lubricate a machine, providing it is neither so rarefied as to provide no lift, nor so near its dew point as to condense within the high-pressure regions of the bearing.

New Books

A short Course in Radiological Protection *by Health Physics Division and Isotope School. A.E.R.E. (A.E.R.E H.P./L.23. 13s. 3d. net.)*

During 1955 it was decided to supplement the services that had been run by the Isotope Division on the industrial application of radio-isotopes and the Health Physics Division at Harwell, which had been giving advice on general precautions and safety measures for specific operations, by running a series of short courses on radiological protection. The first of these was held in November, 1955, and lasted four days. The lectures given have been slightly expanded and published with a minimum of additional editing. As a result, a certain amount of repetition occurs throughout the book which, on the whole, increases its value and minimizes the efforts of the new reader in understanding the various sections. This type of publication has long been needed by workers in the isotope applications field who have had as their guides the International Commission on Radiological Protection recommendations and publications by the Ministry of Labour and National Insurance Factory Department which, though helpful in specifying maximum levels and acceptable codes of practice, are not easily assimilable.

The lectures begin with a short discussion on basic physics principles, itemizing the magnitude of various physical quantities. This is followed by a discussion entitled "Energy of Various Radiations" which gives a very brief analysis of the effects of alpha and beta particles and gamma rays. The "Organization of a Radiation Protection Service" should be read by managements and laboratory heads and points out that it is essential for an atmosphere of confidence and goodwill to be developed in radioactive work with an approach that is neither too cautious nor, on the other hand, foolhardy. It emphasizes that senior people should be very careful to avoid risks brought about by undue familiarity. The chapter on "Units in Radiation and the Detection of Radiation" will be of particular value to those who find it difficult to distinguish between the rad, rep and rem. It is interesting to note that in the section on "Maximum Permissible Levels of Radiation" the discrepancy of a factor of 3 between the m.p.l. for external dose rate and internal fixation of radium is considered to be small. The sixth lecture is accompanied by a series of absorption and shielding curves which will be of considerable value to industrial designers, although it would have been more valuable if the curves for beta rays had been plotted in terms of maximum rather than mean energy. Only brief mention is made of Bremsstrahlung problems, which can cause the source designer some difficulties in shielding. It would have been helpful to include specimen curves of Bremsstrahlung spectrum generated by representative beta emitters and to amplify the comments on conversion efficiencies. The final chapter on waste disposal could be more specific in guiding small laboratories on the policy that should be adopted, but serves to emphasize the absence of facilities in this country for the disposal of highly active waste accumulated by laboratories external to the A.E.A.

Facing the Atomic Future *by E. W. Titterton, Ph.D. (Macmillan, xxix+371 pages, 21s. net.)*

Professor Titterton has attempted the very difficult task of discussing scientific subjects in a scientific manner, whilst at the same time attempting to analyse the sociological implications of new developments. The fly-leaf suggests that "this vitally important work is for the layman", but it is very doubtful whether real laymen would find the initial introduction on "what is atomic energy?" comprehensible. It invariably happens that when an expert is writing for the public, the smooth writing with its inevitable technical jargon, although entirely understandable to the reader familiar with basic concepts, is peculiarly difficult to assimilate by the genuine lay reader. The book has aimed at being comprehensive in its discussion on atomic energy for peaceful and for military purposes and will undoubtedly be read with interest by workers in the atomic energy field who are interested in aspects of the subject other than their own and who are interested in examining the broader sociological problems as well as the merely factual. There is, however, the danger that the book is too broad in its scope to be read in its entirety by many workers in the field and there will be few laymen who will have the persistence to read its 371 pages.

The International Journal of Applied Radiation and Isotopes *(July, 1956. Pergamon Press Ltd., New York and London. £6 per volume.)*

With an editorial board including representatives from Canada, Holland, the United States, France, Russia and the United Kingdom, this journal aims to reproduce articles on the use of radioactive isotopes in the various fields of medicine, biology, agriculture and industry. The first issue, published in July and combining Nos. 1 and 2, contains articles on the preparation and maintenance of standards, tracer techniques for salt and silt movement, a technique for determining specific surface area, aspects of large liquid scintillators, quantitation of autoradiography, gamma-ray vulcanization of rubber, three articles on biological and medical subjects and an article in French on the use of a discriminator in gamma activation analysis. Whilst it is appreciated that an international circulation of this journal is aimed at, it would have seemed more appropriate to publish throughout in one language. Whilst French may be universally understandable, it is doubtful whether many would be able to understand articles written in, say, Russian, which one would assume, from the composition of the board, is likely to follow.

There would appear to be a danger of this journal meeting the same difficulties as the Radio-isotope Conferences at Oxford, which have been characterized by a concentration on the results of experiments rather than the techniques employed. In fact, the Second Radio-isotope Conference, for the most part, resolved itself into a medical and biological discussion. It is to be hoped that sufficient attention will be paid to developments outside the Atomic Energy Authorities and Commissions and the universities and hospitals, so that due credit can be paid to industrial developments. Unfortunately, the rate of progress in the development of new techniques is slow and very little change has been made in general methods of assay and tracing over the last five years. There is room, however, for a critical analysis to be made of the capabilities and limitations of the various types of detection instrument, with due attention being paid to the sensitivity and stability of various types of system and electronic apparatus.

Calder Hall *by Kenneth Jay, M.B.E. (Methuen Ltd. 88 pages, 25 illustrations. 5s. net.)*

In this book, the author, a member of the A.E.R.E., Harwell, has combined inside knowledge of the subject with a gift for lucid exposition to the lay mind—a gift that is by no means as common as one would wish. The product is something which, while primarily appealing to the man in the street, is not without interest to those more familiar with the technicalities of the nuclear field. Furthermore, he has managed to hold this course without allowing himself to be forced by circumstances into wavering between the extremes of abstruse technicalities and sheer puerility—a task that has been too much for many authors.

In these days of high production costs, the publishers, too, are to be congratulated on the achievement of a book of this quality at the price.

Nuclear Energy in Industry *by J. G. Crowther (George Newnes Ltd. 166 pages, 100 illustrations. 17s 6d. net.)*

This book is intended for popular consumption and gives a general overall picture of a very wide field in a manner that is intelligible to the lay and the semi-technical. The opening chapters deal with the problem of available energy on a world basis and the nature of nuclear energy in a very simple and straightforward fashion. The various types of reactor and their broad principles and characteristics are next dealt with, after which a chapter is devoted to the actual generation of power and the various types of plant employed, including the U.S.S.R. 5-MW plant, Calder Hall and a number of future projects. Further chapters deal with the practical applications of isotopes in industry and the winning of uranium. The final chapter deals with the new metallurgy which nuclear engineering has brought in its train and a forecast of the technology of the future.

Oxidation-Resistant Silicon-Aluminium Steels *by E. A. Brandes, B.Sc., A.R.C.S., F.I.M.* (*Fulmer Research Institute.* 10*s.* 6*d. net.*)

This, No. 2 of the special report series of this Institute, gives the result of research on low-alloy steels which, it is suggested, could be applied in place of the expensive austenitic steels. Results have shown that steels containing 2 to 3% silicon with 0.5 to 1% aluminium are comparable in resistance to oxidation at temperatures up to 900°C with 18% chromium, 8% nickel austenitic steel. The results of mechanical tests show that such steels have adequate ductility at room temperature to permit many metal-forming operations and that the ductility is not reduced by oxidation at temperatures up to 900°C. Although the resistance to corrosion in atmospheric and accelerated tests is no better than mild steel, and strength at 600°C is low unless the steels are further alloyed, scaling resistance in flue gas and steam is superior to mild steel and is further improved by aluminium coatings. The report can be obtained from the Fulmer Research Institute at Stoke Poges, Buckinghamshire.

New B.S. on Heat Insulation

The British Standards Institution have issued a revised edition of B.S.874 covering definitions of heat-insulating terms and of determining thermal conductivity. Amongst other alterations included, the methods of measuring thermal conductance and transmittance have, it is stated, been completely revised.

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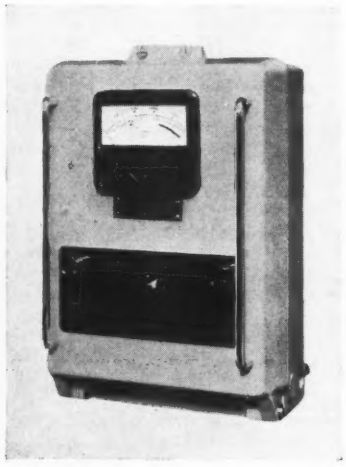
Processes and Equipment

Levels by γ Rays

Gamma rays are used as an operating medium for a liquid-level indicator developed by The Baldwin Instrument Co. Ltd., of Brooklands Works, Dartford, Kent. The particular advantage of this type of instrument is that it is not necessary to locate any equipment inside the vessel; a matter of moment when the liquid is corrosive or at a high pressure.

The apparatus consists of a transmitter unit containing a γ-emitting isotope which



The Baldwin liquid level indicator.

is located on one side of the container and a detector unit on the other which gives a secondary output proportional to the radiation received. This will, of course, be at a maximum when the liquid level is below the beam and will be reduced when the contents of the tank intercept the beam, reducing the radiation received and causing the difference in electrical output of the detector unit to energize a relay which can operate an indicating lamp, as illustrated, or can be incorporated in an automatic control circuit. If desired, two heads can be fitted to show maximum and minimum levels.

Since the operation of this device depends on a change in radiation absorption, it can be applied to detect the boundary layer between two liquids of different densities.

Inflatable Hut

From atomics to inflatable rubber huts may seem a long step but, quite apart from prospecting, there are many construction sites remote from shelter where one cannot pick and choose one's weather. The Numax inflatable hut, manufactured by Elliot Equipment Ltd., of Llwynpia, Rhondda, S. Wales, is built on the lines of an aircraft dinghy, and provides a stable, waterproof, accommodation with a floor space of 30 ft. x 19 ft. and a height of 9 ft. Weighing only 160 lb., it measures 4 ft. 6 in. x 18 in. x 18 in. packed and can be carried in the back of a car. It can be erected by one man in three minutes.

Anti-rust Spray

Aerosol dispensers, such as have been used for insecticides, are now being applied to penetrating oils and rust removers by the Pressurized Dispenser Division of Amber Oils Ltd., 11A Albemarle Street, London, W.1. Aerozene, ejected from the pressurized container in a fine jet (said to give a 4-in. circle at 7 ft.) produces a penetrating foam which, when sprayed on, say, a heavily-encrusted spring shackle bolt has been found to reach the inner surface within a few minutes, the colloidal graphite content ensuring persistence of the lubricating film.

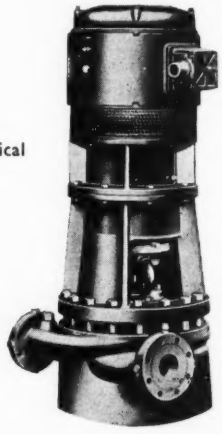
A companion product, Rusolvent, is a fast-acting easing fluid and rust remover, which is also ejected in a closely-controlled spray. The two products are said to be particularly effective in dealing with joints inaccessible to normal gravity- or hand-fed methods. Both liquids are non-inflammable, and the packs retail at 7s. 6d. each.

Hoses for Liquid Oxygen

New techniques in handling liquid oxygen and nitrogen are announced by the Flexibles Advisory Service of Compoflex Co. Ltd., of 23 Northumberland Avenue, London, W.C.2. The new type of hose is intended to replace metallic flexibles with their limited life and increased boil-off, and is composed of layers of square-woven 10/12-oz. Terylene fabric, Melinex (Terylene film) and further layers of fabric with inner and outer helices of 12-g. stainless steel wire. The actual number of layers will vary according to the working pressure, but would be at least ¼ in. for a low-pressure hose. For working pressures of more than 500 p.s.i. an outer braiding of stainless steel would be provided. Bearing in mind that the temperature of liquid oxygen is around −183°C, the heat-insulating properties of the Compoflex hose should be of considerable significance. In addition, the flexibility at low temperatures is considerably improved, it being possible to bend a 4-in. hose to a 3-ft. radius. Manufacture of hoses up to 8-in. diameter is envisaged.

Vertical Circulating Pumps

Latest addition to the Mopump range manufactured by Rhodes, Brydon and Youatt Ltd., of Gossey Mount Street, Stockport, is the 350 vertical series. The vertical arrangement has, it is stated, the



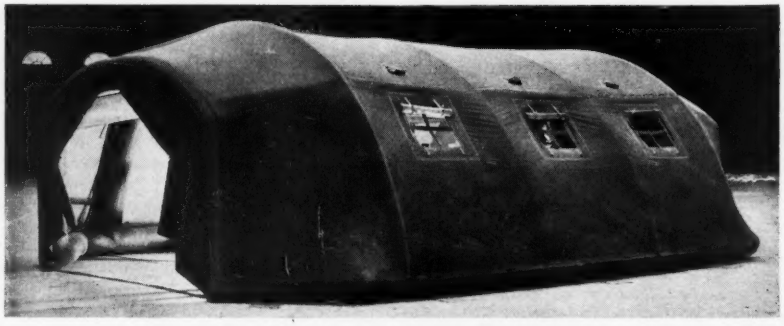
The new vertical Mopump.

advantages of reduced space, increased stiffness, ease of access and the elimination of static deflection, thus simplifying gland sealing. This, incidentally, is carried out by a short stuffing box with four rings of packing, backed up by a long throttle bush, bored to very fine limits, to give a very small annular clearance between shaft and bush, so that only a thin film of water can pass, and assuring adequate cooling of the leakage water as well as providing an effective pressure break-down. The stuffing box itself is water-cooled, as is the main lower bearing, which is of the roller type.

The arrangement of the pump, with the suction and delivery pipes in line but offset from the axis of the pump, makes for easy installation and servicing, it being necessary to remove only the motor to obtain access to the pump without breaking pipe joints. The new range is suitable for hot water at up to 350 p.s.i.

Stainless Steel Weights

Griffin and George Ltd., of Ealing Road, Alperton, Middlesex, are marketing new analytical balance weights made from a



Numax inflatable hut for remote construction sites or prospecting.

25/20 chromium-nickel austenitic stainless steel. This, when highly polished, is said to give corrosion protection equivalent to the more expensive 80/20 Ni-Cr alloy. A further interesting feature is the integral knob, thus avoiding the internal cavity which is frequently a cause of instability.

Portable Neutron Monitor

The Nuclear Instrument and Chemical Corporation, of 223 West Erie Street, Chicago, 10, have sent us particulars of their new Nemo Model 2715 portable survey meter, which is designed to measure thermal and fast neutron fluxes from 10 to 10^4 n/cm²/sec. Measurement of thermal and fast neutrons is entirely separate, there being two proportional counters of enriched barium trifluoride. The fast neutron counter is mounted in a wax block surrounded by a cadmium shield and is sensitive only to neutrons with energies above the cadmium resonance at 0.176 eV. The instrument will give no response in a pure γ flux of up to 100 mr./hr.

The instrument is complete with batteries, and is fitted with a selector switch for thermal-fast change-over and battery test points. A jack is provided for head phones if aural monitoring is required, and there is a pair of neon lamps which light alternately with each detected neutron, permitting estimation of fluxes below 10 n/cm²/sec. The instrument scale is logarithmic.

Nemo portable neutron monitor.

Protective Clothing

Timeg Ltd., of 102 Wardour Street, London, W.1, are devoting a considerable amount of attention to the question of protective clothing for workers in nuclear plants, and the experience of their research department, which has already solved a number of special problems in the oil industry, is at the disposal of companies engaged in the nuclear engineering field who have any problems connected with protective clothing. While they are prepared to supply any type of cotton garment, they recommend Terylene for this service, and point out that four times the life can be obtained from this material as will normally be obtained with cotton under comparable working conditions.

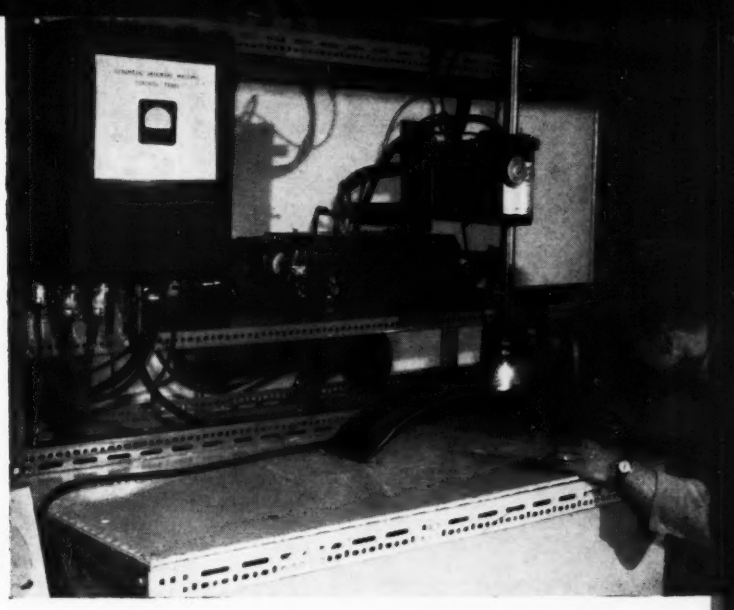
Timeg Terylene overalls.

Nimonic 100

Additional data have been released by Henry Wiggin and Co. Ltd., of Thames House, Millbank, London, S.W.1, on the latest addition to their Nimonic series of alloys. Nimonic 100 is suitable for use at temperatures approaching 1,000°C (1,832°F approx.), its maximum stress (81 tons/sq. in. at 20°C) being 26 tons/sq. in. at 900°C and 8 tons at 1,000°C, and its melting range being 1,310-1,380°C. Its creep properties and rotating bend fatigue properties are also exceptional, the latter, shown by a stress range of ± 14.3 tons/sq. in. at 940°C, having an endurance of 15×10^6 cycles in about 100 hours.

Corrosion-resisting Paint

New addition to the range of manufactures of Supra Chemicals and Paints Ltd., of Hainge Road, Tividale, Tipton, Staffs, is Supruba paint, a chlorinated rubber paint said to have unusual impermeability to water vapour and to provide good protection against acids, alkalis and vapour, and to have successfully withstood the conditions obtaining in gasworks. It is supplied in sixteen shades.



Automatic argonarc welding of contoured part.

Automatic Argonarc Welding

The new Model C argonarc welder developed by British Oxygen gives, it is reported, completely automatic control of this process for the first time. Intended for use on jigged components or contoured sections, the machine is capable of dealing with very light-gauge material due to the close control of arc length achieved.

The unit consists of a water-cooled welding head with a maximum capacity of 400 amp., with motor-operated movements for arc length and head travel; all movements, including water, gas and filler-rod feed, being remote controlled to pre-set conditions. Initiation of the arc may be by allowing the head to touch down or, if desired, high-frequency starting may be arranged. The Model C is intended for D.C. supply, but A.C. operation can be supplied if required.

Further particulars may be obtained from the Technical Service Department of British Oxygen Gases Ltd., North Circular Road, Cricklewood, London, N.W.2.

S.I.F. Cards

The first of a series of reference cards in the Scientific Information File series has just come to hand. This new series is being published by R. B. Winder from 66 Redway Drive, Whitton, Middlesex. This particular card is devoted to the parabola and it covers every aspect with remarkable thoroughness, collecting, on one card, the properties of parabolas, including their co-ordinate geometry, and associated tangents, normals chords, Cartesian and polar equations, definitions, formulæ for areas, lengths of arc and other parts. Engineering applications dealt with include centres of gravity, suspension bridges, the dynamics of projectiles, forced vortices, laminar pipe flow and parabolic reflectors. For draughtsmen, methods of constructing parabolas shown include plotting, string and square, geometrical and tangent construction. The complete information, including references to further published material and some 26 diagrams, is accommodated on a single folding card to fit into a standard 8 in. by 5 in. card index system provided with an index heading on the Holstrom method. The price is 2s. post free, with reductions for quantities.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 755,242. Means for protecting human beings and animals against the biological injuries caused by radiation. S. Missoten (Belgium).

By combining a material for reducing the velocity of the neutrons with a material which is capable of absorbing the slowed-down neutrons, reasonably thin plates, sheets or slabs can be built up which are cheap and effective. The absorbing means (boron, cadmium, lithium or compositions of them) and the slowing-down means (graphite, amorphous carbon, coal, beryllium or compositions of coal and beryllium) may be used in the form of powder or blocks and may be mixed with sand or gravel or heavy and dense materials such as barytes, heavy spar, tailings of iron, steel, lead, etc., providing, in addition, protection against gamma rays and X-rays. A series of layers may be deposited on existing walls.

B.P. 755,439. Rock-drilling apparatus. A. T. Holman and P. Stein. To: Holman Brothers Ltd.

Prospecting for radioactive minerals is usually carried out with a portable radioactivity detector and by removing selected rock samples for assaying elsewhere. In the new rock-drilling unit, the dry rock dust is withdrawn by suction, conveyed through a hose or channel to a dust collector and then monitored for radioactivity by a radiation detector mounted adjacent to the dust collector. The dust may temporarily be collected in a chamber where batches of dust are separately monitored before passing on to a bag or other receiver.

B.P. 755,495. Process of and apparatus for carrying out nuclear reactions. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

This patent refers to a reactor in which the nuclear fuel is circulated in the liquid state; for example, dissolved in heavy or ordinary water or suspended in water or molten metal. Suspensions of uranium oxide in heavy water are especially suitable, but a difficult problem is presented by the pumping of this liquid. One answer is to make the suspension flow under the influence of gravity through the reactor and the heat exchanger. The suspension is then carried upwards to a level above the reactor through a vertical riser into which gas is injected at the lower end in order to "wash" the liquid and remove fission and decomposition products, as some of the fission products (for example, Xe 135) possess a large neutron-absorption cross-section. The gas should yield the smallest possible amount of radioactive products under the influence of delayed neutrons. Suitable gases are O_2, He, CO, CO_2 and N_2; air may also be used in certain cases. When heavy water is present, this and the heavy hydrogen have to be recovered from the injection gas; for example, by catalytic reaction with O_2. Water may be removed by cooling. After subsequent removal of the gaseous fission products, the gas is recirculated by a pump.

B.P. 755,598. Process for carrying out nuclear fission reactions. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

By careful selection of the design and dimensions of the reactor and the initial proportions of the quantities of moderator and fissile material, the susceptibility of the reactivity of the fission reaction to fluctuations in the ratio of the quantities of moderator and fissile material will be minimal, and the reactor can be kept critical by gradually varying the proportions of moderator and fissile material. The susceptibility is kept minimal by gradually diluting the fissile material with a substance containing atoms which, under the influence of thermal neutrons, may change into atoms that are readily fissionable. The reactor is thus kept critical by gradually increasing the proportion between the quantities of moderator (heavy water) and fissile material (uranium oxide).

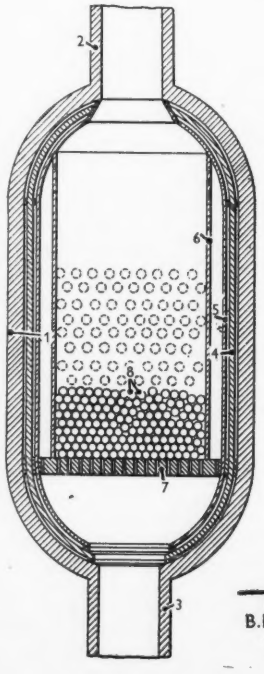


Fig. 1. B.P. 756,014

B.P. 755,967. Method and apparatus for testing the presence of specific atomic elements in a substance. J. L. Putnam. To: U. K. Atomic Energy Authority.

The substance is irradiated with neutrons. The occurrence and energy of gamma rays emitted by the nuclei of the substance under test and by the nuclei of any intervening substance absorbing neutrons are detected by a scintillation counter and analysed in groups to determine the particular n, γ reaction and thus the particular elementary substance corresponding to each group. The apparatus may advantageously be employed for the assay of inaccessible substances, for example, in strata of boreholes through a 2-in. thick steel liner.

B.P. 756,014. Reactors employing nuclear fissionable material. To: Westinghouse Electric International (U.S.A.).

The power-producing reactor described in the specification operates with a closed high-pressure and high-temperature coolant system connected to a high-pressure core vessel. Some heat is extracted in a heat exchanger connected in a primary loop with the reactor core and used, for example, in turbo-generating plant. A high-pressure core vessel is not needed in breeder and other types of reactor. Fig. 1 shows a simplified form of the reactor vessel: (1) is a thick-walled pressure chamber (steel) with an outlet (2) on top and an inlet (3) at the bottom. (4) is an intermediate shielding member, (5) an inner shielding member, both of any structural material (steel, stainless steel), kept apart by spacing members. The core container (6) has a perforated bottom plate (7) on which are placed pellets (8) of fissionable material. The core container (6) is made of a material having a low neutron-absorbing cross-section (aluminium, zirconium), but steel may be used. When the reactor is inoperative the pellets will occupy the lower portion of the container. The fuel elements are then in a non-critical condition. When fluid is admitted under controlled pressure and flow conditions, the fuel pellet bed expands to a critical condition as the pellets are forced upwards, as shown by the dotted lines. The fluid acts as coolant and preferable also as moderator. Water is preferred, but fluid metals (sodium, bismuth, lithium) or organic liquids or inorganic compounds (alkaline metal hydroxides) may also be used. The fluid passes out through the upper outlet (2) and heat is abstracted in a primary coolant system. As the criticality is determined by the balance between neutrons absorbed by the fuel elements which produce fission, neutrons absorbed but not producing fission, and those lost by leakage, when, for example, water is employed as coolant, the degree of criticality can be controlled by varying the ratio of fuel to moderator. When using heavy water as moderator, control is effected simply by increasing the coolant flow to expand the fuel-bed. If ordinary water—which has an appreciable neutron capture cross-section—is used, expansion of the fuel-bed beyond a certain critical amount will decrease the criticality of the reactor. Should the pumping power fail, the pellets would collapse and the reactor become non-critical.